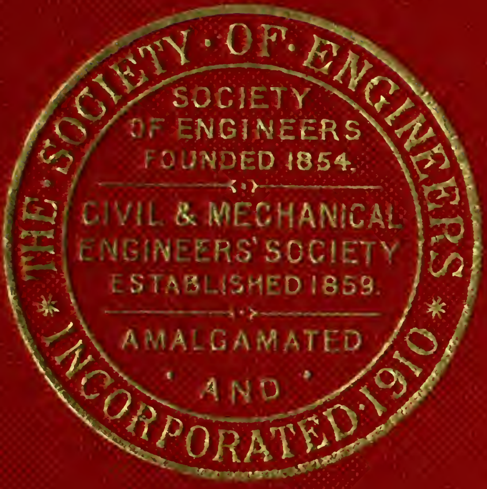

THE · SOCIETY · OF · ENGINEERS
SOCIETY
OF ENGINEERS
FOUNDED 1854.
CIVIL & MECHANICAL
ENGINEERS' SOCIETY
ESTABLISHED 1859.
AMALGAMATED
AND
INCORPORATED · 1910

Presented to
The Library
of the
University of Toronto
by

THE ENGINEERING INSTITUTE

OF CANADA.

THE ENGINEERING INSTITUTE
— LIBRARY —
OF CANADA

Digitized by the Internet Archive
in 2011 with funding from
University of Toronto

http://www.archive.org/details/journalsoe1921soci

THE RIGHT HON. LORD HEADLEY,

President of the Society of Engineers (Incorporated) 1921.

(See page 5),

(THE)

SOCIETY OF ENGINEERS

(INCORPORATED).

SOCIETY OF ENGINEERS: ESTABLISHED MAY, 1854
CIVIL & MECHANICAL ENGINEERS' SOCIETY: FOUNDED MAY, 1859 } **INCORPORATED 1910**

Journal and

TRANSACTIONS FOR 1921.

EDITED BY

ALFRED S. E. ACKERMANN, B.Sc.(Engineering).
A.C.G.I., M.Cons.E., A.M.Inst.C.E.,
SECRETARY.

(All rights of Publication and Translation are Reserved.)

LONDON:
PUBLISHED BY THE SOCIETY OF ENGINEERS
(INCORPORATED).
17, VICTORIA STREET, WESTMINSTER, S.W.1.
1921.

20.6
711

*The Society is not responsible either for the statements made
or for the opinions expressed in the papers or
in the discussions thereon.*

All rights of publication and translation are reserved.

TA
1
S67
1921

LIBRARY
APR 3 1962
UNIVERSITY OF TORONTO

789685

THE SOCIETY OF ENGINEERS

(INCORPORATED).

SOCIETY OF ENGINEERS: ESTABLISHED MAY, 1854
CIVIL & MECHANICAL ENGINEERS' SOCIETY: FOUNDED MAY, 1859
INCORPORATED 1910.

COUNCIL AND OFFICERS FOR 1921.

Council.

President—THE RT. HON. LORD HEADLEY.

Vice-Presidents
TONY JULES GUERITTE.
ARTHUR MARSHALL ARTER.
WALTON JOHN HADFIELD.

CHARLES TROUBRIDGE WALROND.
ARCHIBALD STEWART BUCKLE.
GEORGE NOBLE FELL.
GEORGE ARTHUR BECKS.
FREDERICK PURTON.
HERMANN SLOOG.
CAPT. RICHARD TWELVETREES.
ROBERT HAMPTON CLUCAS.
CAPT. CHARLES CONNOR.
DOUGLAS CHARLES FIDLER.

Member of Council from class of Associate Members—
ROBERT JOHN SIMPSON.

Members of Council, ex-officio.

Past Presidents
(1920) BURNARD GEEN.
(1919) WALTER NOBLE TWELVETREES.
(1918) WILLIAM BEEDIE ESSON.
(1917) HENRY CHARLES ADAMS.

Hon. Secretary and Hon. Treasurer—DAVID BUTLER BUTLER.

Trustees
SIR DOUGLAS FOX.
SIR ALEXANDER BLACKIE WILLIAM KENNEDY, LL.D., F.R.S.
ALEXANDER SIEMENS.

Hon. Solicitors—MESSRS. BLYTH, DUTTON, HARTLEY & BLYTH.
MR. R. H. WILLCOCKS, B.A., LL.B.

Bankers—LLOYDS BANK (LIMITED).

Auditors—MESSRS. BEGBIE, ROBINSON & CO.

Secretary—ALFRED S. E. ACKERMANN, B.Sc. (ENGINEERING).

OFFICES:
17, VICTORIA STREET, WESTMINSTER, S.W. 1.
Hours, 10 *a.m. to* 4 *p.m.*; *Saturdays*, 10 *a.m. to* 1 *p.m.*

TELEPHONE: VICTORIA 244.
TEL. ADDRESS: "WINDOLITE, VIC. LONDON."

THE RIGHT HON. LORD HEADLEY, B.A., M.INST.C.E., I.

President of the Society of Engineers (Inc.), 1921.

Our new President was born in 1855. He gained the B.A. degree by taking the Math. Tripos while at Trinity College, Cambridge, in 1878. After leaving college he was engaged in educational work, and for two years was Editor of the *Salisbury Journal*, Wiltshire, and for seven years was secretary to Sir F. Seager Hunt. Lord Headley is a civil engineer, and has been engaged chiefly on foreshore protection works in England and Ireland. He was assistant engineer to Spedding & Co., Kashmir, on the Baramula-Srinagar Road, in 1896. In 1906 he was appointed engineer to the Arklow Harbour Commissioners.

Lord Headley is the author of several works on foreshore protection and on boxing. He won the Middle and Heavy Weight Championships at Cambridge.

He gained the following Medals and Premiums : Silver Medal of the Royal Scottish Society of Arts, 1900 ; Silver Medals of the Institution of Civil Engineers of Ireland, 1902 and 1903 ; Bessemer Premiums of the Society of Engineers (Inc.), 1899 and 1904.

Monday, 7th February, 1921.

INAUGURAL MEETING FOR THE YEAR 1921.

The Retiring President, Mr. Burnard Geen, A.M.Inst.C.E., inducted the Rt. Hon. Lord Headley as President for 1921, invested him with the President's badge of office, and handed to him the certificate of his election as President.

Lord Headley proposed a vote of thanks to Mr. Burnard Geen for his work as President during the past year, which was seconded by Mr. W. B. Esson, and carried by acclamation. This vote was acknowledged by Mr. Geen.

Lord Headley then presented the premiums awarded in 1920, as set out at page 313 of Journal No. 7, 1920.

PRESIDENTIAL ADDRESS.

By The Rt. Hon. Lord Headley, B.A., M.Inst.C.E., I.

The task of writing a Presidential Address becomes harder each year on account of the rapidity with which inventions of enormous importance follow one another. Time seems to be pushed on one side in these latter years of the world's history : succession of events alone seems to count and the gaps between each startling discovery become shorter and shorter until we reflect with awe on what the climax may be when human intelligence has possibly subjugated and harnessed all the elements with which we are or can ever be acquainted on this earth.

Much of this speeding up of capabilities may be put down to the world war, which sharpened men's intellects to a degree previously undreamed of. The urgency and necessity in every direction led to the application of scientific devices improvised for all kinds of emergencies and hidden potentialities were thus lashed into existence which might otherwise have lain dormant for many decades.

But quite apart from this spasmodic effort of yesterday we can look back on the past hundred years as having provided probably more advances of practical utility than any previous thousand years in the world's history. It is as though we had been privileged to live in an age of miracles and yet, wonderful though it all is, there is an explanation. For one thing the number of scientific brains at work has been greatly increased during the past few years, and the cultivation of those brains has been attended to in a way previously unknown and impossible. Then, again, each fresh scientific discovery swells the stock in trade of the inventor, gives him more material to work with, and therefore more chances of arriving at combinations leading to entirely new devices for specific purposes. As an instance, take the X-rays, discovered by Roentgen, in 1895, The moment this wonderful discovery was reduced to practical application, surgeons were placed in a very much more easy position when dealing with wounds and fractures and other ailments to which the human frame is subject: they were presented with a new field of discovery which led to countless other inventions and appliances for surgical use.

The detection of flaws in metal by means of these or similar rays is another application of the wonderful new discovery.

Wireless telegraphy has proved of incalculable value to the mariner, and, in the presence of these and other marvels, it would be a bold man who would say for certain that we may not one day be able to see through a brick wall or round a corner —such things seem impossible, but it is not so long ago that flying and sending a message without a wire were looked upon as impossible. Experiments with new substances such as radium, uranium and thorium have, within the past few years, led to such marvellous results that our preconceived ideas with respect to matter and motion seem destined to change or modification. When we learn that an almost infinitesimal particle of a certain substance can do work and incessantly give off energy and light and yet show no perceptible change or diminution in weight or power for a period of over two thousand years, we seem to be face to face with a paradox. Here we have a particle from which brilliant rocket-like sparks are constantly being thrown off with great rapidity; there is combustion and one would imagine there must be a residue of some kind, and yet we are told that the scintillation of minute "fireworks" are capable of unceasing illumination for thousands of years!

To Sir Ernest Rutherford and Mme. Curie are due the most advanced steps, and to them we owe most of our present knowledge of radioactivity. Professor John Cox has collected a great number of facts in his fascinating little book, "Beyond the Atom." In that work, which is a veritable vade-mecum for students, he points to the striking fact that both the beginning and the end of the nineteenth century—pre-eminently the century of advance in physical science—were marked by extraordinary outbursts of fundamental discoveries. Let us, then, note a few events which may be found grouped within a year or two of the turn of the eighteenth century.

"1798. Rumford and Davy upset the caloric theory of heat, proving that it was a mode of motion affecting the molecules of the hot substance.

1799-1802. Young upset the corpuscular theory of light, proving that it was a wave-motion in a new medium —the ether.

1800. The concept of energy was first introduced by Young. Volta discovered the electric pile, Rumford founded the Royal Institution, which, in the opinion of good judges, has done more in the century to advance physics than any single University or other body.

1802. Wollaston first noticed the dark lines in the solar spectrum, thus laying the foundation of spectrum analysis.

1803. Dalton brought forward the atomic theory, giving a vast expansion and impetus to chemistry."

The turn of the nineteenth century has a group to match :—

"1878. Crookes produced the Kathode-rays, claiming that they constituted a new, or fourth, state of matter—radiant matter.

1893. Lenard, following up Hertz's discovery that Kathode-rays could pierce a thin sheet of metal, brought them outside the vacuum tube into the air.

1895. Roentgen, repeating Lenard's work, discovered almost by accident the X-rays, and worked out their chief properties.

1896. Becquerel discovered radioactivity in uranium.

1897. J. J. Thomson proved that the Kathode-rays consisted of particles a thousand times smaller than the atom of hydrogen—the smallest atom known.

1903. Radium was discovered by M. and Mme. Curie.

1896-1906. Rutherford and Soddy established the disintegration theory of radioactivity, thus founding a new science of sub-atomic chemistry."

The work of the intervening century brought to light some capital and many minor discoveries. It may be said that 1821 was the coming of age of "electricity," for it was in that year that Oerstedt found the first connection between electricity and magnetism in the effect of a current on a neighbouring compass needle. Ten years later, in 1831, Faraday, in a fortnight's work, laid bare the laws of the induction of currents. His book on this subject is one of the most important and interesting works ever written, and is strongly recommended to all students of electricity—both from the historic point of view and as a handbook on fundamentals. Later on he found, after much research, the first link between electricity, magnetism and light, and these problems were afterwards brought into one domain by Maxwell's "Electro Magnetic Theory of Light," which received a splendid verification in the experimental researches of Hertz. Amongst the works of Professor Faraday may be enumerated :—" Experimental Researches in Electricity," 1844-55 ; " Experimental Researches in Chemistry and Physics," 1859 ; "Chemical History of a Candle," 1861, " Various Forces in Nature," etc.

The nineteenth century was occupied mainly with developing and correlating the leading ideas and discoveries which emerged at its birth. To realize the progress made, one must contrast the physical ideas current in 1800 and in 1900. In 1800 mechanics had already reached a commanding development, and all explanation, even in the more backward sciences, was based on Newton's view of *action at a distance* as seen in gravitation. Sound and light were, indeed, explained mechanically, sound by vibrations of the air, light by the impact of corpuscles. But heat, electricity and magnetism were still isolated regions. Their mysterious properties were attributed to imaginary substances—caloric, the electric fluid and magnetic matter—which, because they did not affect the weight of the bodies in which they resided, were known as the *Imponderables.*

In 1900 action at a distance is still employed as a useful figment in mathematical calculation. But the imponderables are gone. Heat is molecular motion, light an ether vibration, magnetism ether whirls, electricity ether strain or ether shear. Matter itself may be vortex rings in the ether, or, perhaps, of electrical origin. Thus mechanics has invaded the whole field, but it is the mechanics of molecules or of the ether. By extending the laws of motion derived from the study of bodies of sensible magnitude to the molecule and ether, hypothetical entities for ever far beyond the limits of direct sense perception, a wonderful simplification has been effected.

Professor Cox points out that the advance has been along two main roads, each lighted by a constellation of seven great names. One of these ways is through the mechanics of molecules, covering the theory of heat and the gaseous laws. It was beaten out by Rumford, Mayer, Joule, Helmholtz, Carnot, Kelvin and Clausius. The other track lies through the mechanics of the ether, to the modern theories of light, electricity and magnetism. Its pioneers were Young, Fresnel, Ampere, Faraday, Kelvin, Maxwell and Hertz ; and midway in the map of the century stand the two great landmarks :—

Conservation of energy ...	...	1847,
Origin of species ...	...	1859.

The preliminary survey of the general course of physics in the nineteenth century is followed up in the delightful pages of Professor Cox's book by an enquiry into the more recent discoveries bearing chiefly on the atomic structure of matter, and tracing in outline the steps by which physicists have been led to advance beyond Dalton's atomic theory and proceed beyond the atom. We are told that for the purposes of the chemist the atomic theory is as serviceable to-day as it has been throughout the century, in spite of the modifications which recent work has compelled in our conception of the atom. The molecule (or, in the case of elements, the atom), has been employed to elucidate those properties of matter which fall short of chemical change. The facts of cohesion indicate that molecules can exert enormous forces of attraction on each other, but only when brought within inconceivably minute distances. Thus a broken solid cannot be mended by forcing the parts together by hydraulic pressure, however great, for the molecules cannot be brought again within the range of their mutual attractions. In solids the molecules, or, at least, most of them, are permanently anchored in fixed positions, locked together by their mutual forces; and yet are in perpetual agitation, either of vibration or rotation, about those positions. It may seem outrageous to claim that a block of gold or lead, apparently so quiescent, is really the theatre of violent tremors and motions among its myriads of particles. But the senses are not safe guides. The eye cannot discriminate the spokes of a wheel in comparatively sluggish motion, and there is plenty of evidence that the molecules do travel, even in solids. If a block of gold be left in contact with a block of lead and examined from time to time, traces of each metal will presently be found throughout the other. In liquids, though the bonds are partially relaxed and the molecules may slip freely over each other from one point to another, they are never far enough to escape the constraint of their mutual forces.

To give some idea of the size of the constituent parts of matter we have the following :— :—

"About two million molecules of hydrogen in a row would occupy a millimetre, *i.e.*, the twenty-fifth of an inch. Fifteen thousand million million million of them would weigh a grain. When the gas is at freezing-point each molecule makes on the average, 17,750 million collisions per second, at each of which its speed is changed and diverted. Yet, on the average, it has a speed of over six thousand feet per second, moving about a quarter of a millionth of an inch between collisions. The number of molecules in a cubic inch is about six hundred million million million. And this number holds for all gases, since one of the consequences of the kinetic theory of gases is Avogadro's law, that the number of molecules in a cubic centimetre at a given temperature is the same for every gas." To attempt to follow the learned Professor through descriptions of the various processes and experiments by means of which the emanations and rays from uranium, radium, thorium and actinium may be examined and measured would be altogether outside the scope of this address, but it may be admissible to give a further excerpt from Cox's book in order to form an idea of the amount of patient research which was necessary before the new rays were discovered.

"The Austrian Government presented M. and Mme. Curie with a ton of uranium residues from the State manufactory at Joachimsthal, and there ensued a long and laborious search for the suspected trace of impurity. Endless precipitations and fractional crystallisations were employed, the active agent being unerringly tracked down by testing the activity of the precipitates and residual solutions at every stage, until the patient ingenuity of the investigators was rewarded by the separation of a few milligrams of two active bodies to which Mme. Curie gave the names polonium and radium, the first in honour of her native country, the second, by a happy inspiration, on account of its extraordinary power of radiation, more than a million times that of uranium. The radium was obtained in the form of a chloride. All there was to show for months of labour on a ton of materials was a minute pinch of white powder, at present worth £15 a milligram, or about £1,000 a grain. But its properties amply repaid the toil. Its radiations light up a flourescent screen brilliantly, blacken a photographic plate, and instantly ionize the air in its neighbourhood. A few milligrams carried in the pocket will soon produce a deep abscess in the side, as M. Becquerel found when he brought some from Paris to London for a lecture at the Royal Institution."

The Harnessing of the Electron.

From the foregoing it will be sufficiently apparent that the researches made possible by the discovery of the new substances and their emanations open up a field of vast extent and indicate the possibility of controlling and using new forces hitherto unsuspected by scientists. My admiration of those pretty lines :—

"That very Law which moulds a tear
And bids it trickle from its source,
That Law maintains the earth a sphere
And guides the planets in their course,"

is as great as ever, but there seems now an added conviction that the law of universal gravitation is to be supplemented and possibly strengthened. As engineers we are all on the look out for some methods of improving upon our present control of the elements : some new force together with the means of adapting and controlling that force may enable us to undertake works far in advance of our wildest dreams of to-day.

Strutt's radium clock, said to be the nearest approach to perpetual motion hitherto attained, is an example of power obtained by radio-activity, and my friend, Mr. H. V. Kramer, of the General Electric Co., has recently designed an instrument which demonstrates the ionization power of radio-active substances.

We are told that the electron, which is to play so important a part in future investigations, is one hundred thousand times smaller than the atom and the spaces between electrons, perhaps one hundred million times the diameter of an electron.

Mr. Kramer is one of the leading authorities on electro-magnets and radio-activity, and from him I have received the following which I gratefully acknowledge as a most valuable contribution to my address.

" We are asked to accept a far-reaching new theory on the atomic structure of elements. We are now told that the atom is no longer the final smallest fraction of an element, and that elements have not been created as such, but that all atoms alike are composed of a number of infinitely small particles called 'electrons,' the actual number of which present in any single atom determining the particular element.

" If we could, for instance, add or subtract electrons from an atom, we then would instantly convert one element into another, having a higher or lower atomic weight owing to the increased or decreased number of electrons in the individual atom. In other words, the pen-ultimate indivisible smallest unit of all elements is now the electron. Everything in this universe is thus composed of electrons, their number and relative constellation forming the body or object we perceive.

" Sir J. J. Thomson, of Cambridge, has given this original theory to the world, and a great many scientists of high reputation have accepted it.

" The metaphysicist, however, is still pessimistic and glories in the meantime in the hypothesis that even electrons may be further divisible matter and may, perchance, be a lively assembly of some other constituents of which we have to-day neither proof nor even the remotest idea.

" It may, therefore, suffice in the meantime that we have arrived at the earliest signs of a dawn to a new era, and let us occupy ourselves contentedly with a thorough examination and patient research work concerning the electrons, their properties, their influences on known matters and forces, and let, perhaps, without incurring the wrath of Zeus, our phantasies ramble a little into the mysterious regions of the immediate future, and guess what new gigantic force is at present on the knees of the gods for us.

" What definite results can be put forward to-day on the behaviour of the electron since its subjugation during the last twenty-five years ?

" Well, it does not take me long to relate what we learnt—although much serious thought and the most patient and conscientious research work has been invested by the pioneers of the new electronic theory, deserving deep gratitude from the generations to come.

" We know :—

" 1. That electrons actually do exist and as such can be discriminated from the matter ; they can be collected and induced to perform specific work at our bidding.

" 2. That their volumes, specific gravity, and speed at which they travel are definite and on record.

" 3. That the atoms of only two or three elements during our lifetime are, at present, disintegrating, and that during their process of breaking up, lasting several thousand years, they produce the electrons naturally and quite voluntarily.

" 4. That the action of their collisions on their travels through air or solids, causes changes in the medium they pierce, owing to their great speeds at which they issue from the womb of the pregnant atom.

" 5. That they possess electrical properties and answer to electric and magnetic forces.

" 6. That they have a mysterious influence upon the protoplasmic cell.

" The most ardent desire, therefore, of every student or experimentalist of radio-activity is to find means and ways to extend the above six proofs into other fields and also to develop the present attainments for useful service to mankind.

" The ignoramus or the cynic would probably smile at such abstract statements of a twenty-five years' record. He asks for something more tangible, and for his conversion we can only give him prospects calculated from the figures yielded by the investigations and tests made with the few electrons accessible to us by Mother Nature.

" Harnessing electrons on a large scale similar to the potent powers latent in coal, requires still the search after ' Aladdin's Lamp ' to unlock the atoms and compel them to liberate their electrons.

" Why have the atoms of radium and thorium become unstable, and why should they only liberate and give up to us so sparingly their wonderful electrons ? Why can we not smash up the multitude of other atoms and so command prodigious forces ? How and when can we break the strong chain by which the law of Nature safeguards still the atom from our interference ? And yet again, why does nature show us that such chains have been unfastened in the few radio-active substances known to us ? Suppose now we were in a position to sever that chain at will, then the earth will deliver up to us another new force, indeed, greater than any other which man with his never-ceasing ambitions has mastered.

" We can only vaguely conjecture what the destruction of an atom would mean, when we consider the weight of one single electron and its relentless speed.

" It is always very difficult to visualize abstract terms, and instead of referring you to the relative mass of an electron as compared with that of an atom of hydrogen—both being so unthinkably small, I will try and give you a more concrete example.

" Suppose for a moment that we can collect a quantity of electrons, say, 1 cubic centimeter in volume, or as much as can be conveniently put into the cavity of a teaspoon, you will be astonished to learn that this small amount would weigh 34,000 tons. Then let me add that the average speed of a Beta particle or that of a negative electron being 60,000 miles per second, such a great mass of nearly 34,000 tons occupying so small a space, and travelling at such enormous rates, would produce some lively work, if not, irreparable damage to at any rate a portion of this little planet of ours. And all this energy from one teaspoonful of electrons.

" Its energy would be equivalent to the total output of a power station of approximately 1,000,000 amps during a period of 200,000 years.

" It may interest you to hear that I have just constructed a little instrument which demonstrates the ionization power of radio-active substances.

" A paltry few electrons sluggishly released from a feebly-radio-active substance are encouraged by the proximity of a positive charge of the Birmingham City Electricity Works, and they ionize about ten cubic inches of air. In this process the escaping electrons from the radio-active powder used, smash up the molecules of their surrounding air and release from them, by constant violent bombardment, other electrons, and so accumulate gradually an electrical charge, which is manifested in the form of movement of a weighing beam similar to that on a sensitive weighing balance. This ' electronic balance ' moves up and down about 2-3 times per minute, and would work about 2,000 years for the expenditure of about one pennyworth of electricity. The work done is equivalent to about one millionth of a h.p.—without the radio-active substance the instrument refuses to work.

" Although such instruments at the moment are purely for use in research work and have no commercial value or practical application, yet they demonstrate to us essential and wonderful principles in these yet early and ignorant days of radio-activity.

" Let us not forget how James Watt foresaw in the sluggishly dancing lid of his tea-kettle the cradle of his mental offspring—the steam-engine, which to-day, on the coming of age of steam power, is seen in the engineering monster of a 50,000 h.p. steam turbine.

" Let us hope, ere the world grows much older, that little ' electron ' may beat brother steam in as short a time from now."

I have for a long time thought that we may soon be in possession of simple methods of collecting supplies of energy from the air or water during transit, and that transport of all kinds may be enormously accelerated and cheapened by this means.

But the question arises as to whether it is advisable to trust to the world, with its large percentage of evil-minded and malicious persons, the manipulation and control of such terrific powers as those we have been considering. It is humiliating to reflect that, after all the centuries of religious training, one fails to see brotherly love existing in such large quantities as to warrant the universal use of a power so stupendous. The opening of the twentieth century has been marked and is still being marked by exhibitions of savagery quite equal to any we read of in earlier days. Modern science has, indeed, marched with deadly effect in the matter of the destruction of human life in time of war, and, by a process of inducive reasoning, it might well be argued that in the future, when the dogs of war in the shape of harnessed electrons, are let loose, not a single human being will survive on any battle-field. A general officer sitting at his comfortable desk in the War Office, might touch a button and release destructive agencies capable of sweeping hundreds of square miles and depriving of existence every living creature thereon.

It is said that Sir Oliver Lodge and Lord Kelvin have calculated that there is energy enough in every ounce of matter of whatever kind, whether an ounce of metal, an ounce of water, or an ounce of wood, to lift the whole British Fleet from the surface of the sea to the top of Mount Everest—the highest mountain in the world ; also that there is enough latent force, in the shape of atomic energy, in your little finger to run all the trains in the United Kingdom for several minutes, and that there is sufficient atomic energy in an ounce of matter if properly controlled, to keep the largest liner in the world going at full speed for a whole week !

This electronic energy has been described as the world's greatest and most terrible secret—so great and so terrible that it has been seriously put forward that scientific research in this direction should be stopped until it is felt that the human race is sufficiently elevated to be entrusted with the keys of such fearsome store-houses of power.

The contemplation of the worlds of the infinitely minute and the infinitely immense—the electron and the stellar regions—bring equal bewilderment to our finite minds. The Gamma rays command as much respect as infinite space, and we are led to believe that there is a great similarity between the courses of the planetary system and the behaviour of the minute particles of an atom. There is always a consolation to be obtained from the thought that it is easier to imagine infinite space than it is to form any sort of idea as to what might constitute the "limit to space."

In such contemplations one's mind wanders and one's fancy roams towards thoughts of the origin of life and the possibilities of communication with entities which may have had their being on this earth or elsewhere. Certainly when one finds highly scientific and thoughtful men, like Sir Oliver Lodge and Sir A. Conan Doyle, convinced of the possibility of communicating with the departed friends or relatives who may be separated from us by very small or very great distances, and to whom time and space are possibly immaterial, one cannot help speculaing on the possibility of a linking up of the spirit world by the refinement of scientific investigation and trial.

For instance, to myself, as a layman, it seems conceivable that the spirits of the departed may be composed of electrons of a type not altogether different from those inhabiting our earthly bodies. Is is altogether beyond the bounds of possibility that there may be a similarity between the spiritual and the earthly electron sufficiently pronounced to admit of intercommunication ?

Following up the above idea, which had been in my mind for some time, only as recently as last October I came across an account which appeared in the "Scientific American" of an interview with Mr. Edison, the great inventor, who is said to have been searching for an apparatus enabling him to communicate with the spirit world : he is reported to have said :—

"My apparatus is in the nature of a valve ; the slightest conceivable effort will exert many times its initial power for indicative purposes. It is similar to the modern power house, where a man with one-eight-horse-power starts a 50,000 h.p. engine.

"My apparatus will magnify the slightest effort which it intercepts, and give us whatever form of record we desire. I do not wish to explain further at this time. A collaborator on this work died the other day. He knew exactly what I am after. Therefore, I believe he might be the first to use the apparatus, if he was able to do so. Mr. Edison further explained that his asumption of survival after death was based on the belief that human bodies are composed of myriads of infinitesimal entities, each in itself forming a unit of life. These entities live for ever, you canot destroy them any more than you can destroy matter. We are simply working on the same supply over and over again. We change the combination, but we do not change the relative quantities, and they are always the same entities. The reason why I am Edison and you are somebody else is because each has a different swarm of these entities.

" It has been conclusively proved that our personality resides in that part of the brain known as the fold of Broca, and it is therefore, reasonable to suppose that our directing entities are located there. It is these entities which give us our mental impressions and personalities. What we call death is simply the departure of all those entities from our bodies. The whole question of survival is what happens to the master entities in the fold of Broca. It is fair to assume that the other entities from all parts of the body, doing routine work, disband at death and depart to seek new work. But how about the personality entities in the fold of Broca ? Do they break up and seek new work in the universe ? If so, I fear our personality does not survive ; but if they hold together then our personality continues to exist, and my machine ought to be of some use."

If any excuse is needed for the length of my remarks on the excerpts, I hope it may be found in the fact that radio-activity is at this moment engaging the close attention of the greatest intellects in the world and that the theoretical science of to-day often becomes the applied science of to-morrow.

Transport.

The exorbitant rates charged by railway companies for the carriage of goods of all kinds must be held responsible for much of the trouble in this country. For years past the Inland Transport Rates in the United Kingdom have been about double those charged in any other country, and the British producer has thus been handicapped and placed at the mercy of the foreigner, who can always undersell him in the markets. The farmer, the manufacturer and the trader all suffer. How can we blame the farmer for not cultivating much of his land when he finds that all the profit is rubbed off his produce in transit ? Only the other day my attention was drawn to the fact that a certain manufacturer found it cheaper to send goods from any part of Germany to a certain town in England, than it was to send the same quantity of goods from London to that particular town ! What affects the farmer and manufacturer must also affect the trader, and, through him, the consumer.

The main cause of this lamentable state of affairs is the extravagant and obsolete methods adhered to at the terminals, where shunting, marshalling, handling and cartage and overhead charges run away with the money. As an instance, we learn that the carriage of a ton of goods from Leeds to London may come to over £2, and of this sum only about 8d. could be put down to actual *haulage* comprising locomotive, coal, oil, permanent way upkeep, driver and fireman.

With the view of doing away with this waste, Mr. A. W. Gattie devised a system by means of which most of the costly shunting could be dispensed with and an enormous saving effected. Mr. Gattie proposes to do the sorting by means of a clever combination of electric cranes, patent sorting " truckers " and motor lorries. He also economises space by utilising the third dimension of space—the principal sorting being effected on floors one above the other. The principle is that of the Bankers' Clearing House, only the machinery provides a means of doing with heavy merchandise exactly what the bankers' clerks do with slips of paper. The machinery of Mr. Gattie's system is extremely ingenious, and there is ever reason to believe that it would prove an incalculable boon to the country could it be brought into play on a large scale. It is not my intention to attempt to go into details in this address, but rather to indicate one of the most prominent efforts of the present century in the direction of utility and economy.

After a great deal of pressing the Board of Trade appointed an expert committee to make a full and exhaustive enquiry into the merits of the Gattie system. This Committee sat for fifteen days between the 20th of August, 1919, and the 25th of the following October. Sir James F. Flannery was the Chairman, and Sir John Aspinall, Mr. A. W. Burgess, Mr. F. T. Hopkinson and Sir Philip Nash made up the Committee. Many witnesses were examined for and against the scheme and, in the end, the Committee refused to recommend the establishment of a central clearing house in London, chiefly on account of the huge capital expenditure required, the displacement of a large population, and general impracticability.

The result of the enquiry was naturally disappointing to many of those who were convinced, and are still convinced, that enormous saving may be effected by clearing houses in all large centres of distribution. Possibly, when the working capabilities of the machinery have been tested on a small scale so as to prove incontestably that the combination can stand the racket and rough-and-tumble of heavy goods in actual transit, there may be fresh developments leading to vast economies. It has been the opinion of many of the advocates of the Gattie system that the thin end of the wedge principle should have been applied from the very first, and that, had that course been pursued, we should have the benefit of the invention at this moment. Inventors have much to contend against in this country, their principal opponents being State apathy and vested interests; abroad, and especially in Germany, the greatest encouragement is given to promising inventors. Here, obstacles are carefully placed in the way, there new ideas are welcomed.

Another useful invention of recent years is the Kearney High Speed Railway.

The inventor of this system, which seems especially adapted for passenger traffic beneath rivers or to take the place of the costly tube systems at present in use in large towns, claims that higher railway speeds are wanted and that his single rail, with guide rail vertically above it, together with the use of suitable gradients, is capable of affording the advantage claimed. The desirability and usefulness of rapid transit requires no argument in its favour—the progress and well-being of a country depend upon the facility with which ideas, commodities and persons can be exchanged or moved from place to place.

One great advantage of the system is that passengers are able to enter the carriages on the street level and the sinking of expensive shafts with lifts is dispensed with. The cost is about half that of ordinary tube lines, but those interested in passenger traffic—and who is not—are referred to Mr. Kearney's paper to the Society on the 17th of December, 1917. A perusal of this paper will explain the saving effected by the fuller use of the force of gravity and elimination of much waste and loss through friction. The scheme is one which cannot fail to enlist the sympathy of thinkers and workers both on account of the ease of transport, the cheapness, and the great saving of time at present often wasted in waiting for the ferry to cross a river.

It has been often pointed out that the acceptance of any novel or unexpected application of a sound principle always takes time in this country, and the time seems unreasonably long to the inventor who probably sees a long way ahead of the general public. All scientific inventions, without exception, have had to fight against unworthy rivalry and vested interests, and the stupidity of departments which have a knack of appointing the most unsuitable persons to enquire into schemes of a scientific nature.

Water power is likely to take the place of coal or oil in the near future, and in all places where there is a considerable rise and fall of tide or where, as in Switzerland, Norway, India, and other countries, there are inexhaustible supplies of water for impounding and dynamos will be run and electric power supplied over large areas. The latest idea is to generate electricity by harnessing the River Severn and making use of the tides. The promoters of this enterprise anticipate being able to supply the West of England as well as parts of Wales and the Midlands with cheap power. The Severn barrage, as the scheme is called, will, if it ever matures, mark a new era in this country, and will certainly render us to a great extent independent of coal and oil. The falls of Niagara have for a long time been able to supply power to great distances—several hundred miles—though there is a loss due to friction when the distance is considerable. It seems probable that the amount of power generated will be available in London, and that it will give a tremendous impetus to all industries, more particularly in the west country. The fact that such energy as that contained in the mere rise and fall of the tide each day should go to waste is contemplated with regret by all inventors who have ever considered the question. The power is there in almost boundless quantity, but it is un-get-at-able; it is only when we have an estuary or narrow arm of the sea that we seem able to devise methods of collecting and applying it. The Severn, like the Seine, is celebrated for its "bore," a sort of tidal wave which moves up the river to a point far above Gloucester. This bore sometimes causes a great deal of damage, especially to shipping and small boats if all has not been made "ship-shape" in anticipation of the visitation; and, no doubt, it will give much anxious thought to the engineers who are working out the details.

The Channel Tunnel is another of the big undertakings which will almost certainly mature within the next decade. It has been talked of for a hundred years or more, but it is only within the last forty-years or so that it has advanced from dreamland into the realms of practical engineering. The idea has always found favour in France, all the opposition has come from this side of the Channel—several of our leading military authorities considering that the tunnel might facilitate foreign invasion. Before the war, in 1913, a deputation of ninety members of Parliament approached the then Prime Minister, and advanced the opinion that it was in the interest of the country that this great means of communication should be started as soon as possible. It was pointed out that the movement was not in any way a "party" affair, that it would be to the advantage of our commerce, and that many Army officers and others who were, in past years, opposed to the undertaking, were now its warm advocates. The Prime Minister was guarded in his reply and prudently pointed out that it was impossible altogether to lay aside the opposition shown by previous Governments to the tunnel scheme, which was being actively pushed on between 1875 and 1880, and then suddenly relinquished. He mentioned that Lord Wolseley, the great authority on military matters, had been a most determined opponent of any project of piercing the tunnel and destroying what he regarded as Great Britain's security. To quote Mr. Asquith's actual words:—"You ask our Government to reverse the decision of a quarter of a century. Of course, this is a matter which is not to be lightly undertaken; there are new factors and one of them, perhaps the most hopeful, and in some ways the most important, is the establishment on a solid, and, I believe, unshaken basis of our friendship with France. Of course, the potential enemy in the apprehension of Lord Wolseley, and those who adopted his view, and the potential enemy whose power of offence and aggression would or might be assisted by the tunnel, was France. The possibility of such an enemy has faded away through the excellent and cordial relations, which, ever since the agreement of 1904, nearly twelve years, we have maintained between the two countries, ourselves and our friends on the other side of the Channel. There are, again, I consider, other new factors in relation to forms of naval and military warfare, and the source and distribution of our food supplies which undoubtedly deserve consideration."

Doubtless the Prime Minister was alluding to the possibilities of aërial warfare and communication, for the coming of the aeroplane, as Mr. Grahame-White has observed, has quite swept away the old argument that England's strength resides in her isolation. It is almost unnecessary to point out that in all very large undertakings of this nature—for the tunnel will cost probably over £20,000,000, and take seven years to build—the first thing is to prove the utility and commercial benefits which may be reasonably anticipated as a result of the venture. A second point is to prove conclusively that the undertaking is feasible and not fraught with danger to the country.

Of course, it is apparent that Mr. Asquith's allusion to our friendliness to France was true for 1913, but its force has been increased tenfold since our sons have fought side by side through a prolonged and terrible war, and we have emerged victors to share hand-in-hand any blessing which may be hoped for at the end of a righteous contest.

With regard, then, to desirability of constructing the tunnel in the present day it will be instructive to go back to a short consideration of the most valuable evidence given by the late Sir Robert Giffen before the Joint Select Committee of 1883 as to the benefits which the tunnel would confer upon British commerce. This eminent statistician showed that the population of Europe in 1883 was about 300,000,000. In that year the population of the United Kingdom was 35,000,000 (in 1911 it was 45,000,000), and that of North America was about 60,000,000. So that, taking all Europe together, there were about 300,000,000, upon one side, and taking the United Kingdom and North America together nearly 100,000,000 on the other side. The imports and exports between this country and the Continent amounted to rather more than £300,000,000—£166,000,000 imported and £134,000,000 exported. Between the United Kingdom and the Continent of North America on the one side, and the whole of the Continent of Europe on the other, the shipping entries and clearances reached a total of £400,000,000. From Germany, Holland, Belgium and France, the total imports into the United Kingdom amounted, in 1881, to £98,000,000, while the exports were £88,000,000. The exports of domestic produce alone were £50,000,000, and the exports of colonial and foreign produce were £38,000,000, therefore an enormous amount of our distributing business was with those four countries, while in respect of transhipment trade, the imports from the same countries amounted to £8,000,000, as compared with £9,500,000 from the whole of Europe; and the exports to those countries amounted to £2,000,000, as compared with £2,800,000 to all Europe.

Again, almost all the bullion trade with Europe was with the same countries, and of our total trade with Europe, amounting to £300,000,000, about £200,000,000 was with Germany, Holland, Belgiun and France. It is interesting to learn that as regards the trade of the nine ports closer to the Continent than others in the United Kingdom, viz., London, Dover, Folkestone, Harwich, Littlehampton, Newhaven, Rochester, Southampton and Weymouth, Dr. Giffen stated that of our total imports from the four countries which he had specifically mentioned (£98,000,000), £72,500,000 came from those nine ports; and of the total exports to the same countries (£88,000,000), £48,500,000 went from the nine ports. In other words, three-fourths of the imports, and about one-third of our domestic exports, with about four-fifths of our foreign and colonial commerce with those countries were coming in and going out of those nine ports. Sir Robert Giffen expressed his inability to form an estimate of the proportion of traffic passing between the nine ports which might be attracted by the tunnel, but he gave it as his opinion that with a probable increase of trade the new route might have considerable traffic without very much diminishing the quantity of goods going by other lines. In his opinion the tunnel was in the nature of a bridge instead of a ferry, which is universally recognised to be one of the most important improvements that can be effected in transit. In the case of short ferries the substitution of a bridge is always enormously to the advantage of the traffic. The analogy between a bridge and the proposed tunnel is obvious.

A few years ago it was my privilege to have a long conversation with Sir Francis Fox who quite convinced me that his proposed " water lock " was an ample protection against any possible invasion, whilst it did no harm to the tunnel itself. The idea is as simple as it is effective. A short length of the tunnel near the English shore would be depressed or dipped sufficiently to admit of its being flooded and thus rendered impassable during such time as it might be thought necessary; as soon as the danger was passed the water could be pumped out in a very short time, and the way cleared without any damage whatever.

It was estimated at one time that the expenditure of three or four million pounds would be necessary to guard the mouth of the tunnel with military protective works, but it is hard to see where the need of such precaution comes in with the water lock above alluded to. Sir Francis has written several valuable papers on the subject of tunnelling, one of the most important being his contribution to the Royal Institution, entitled, " The Great Alpine Tunnels." To quote his words :—" At the outset, I wish to state that neither Baron d'Erlanger nor I, nor any of our colleagues would entertain this project for a moment if we thought it was going to injure our position as a nation. But, on the other hand, if it should prove, as I believe it will prove, something which will add enormously to our national safety and security, then I think everyone will agree that it is a matter to which the most careful consideration should be given by the Government, by the Committee of Imperial Defence, and by the nation at large."

The Channel Tunnel will come in time, but, like the New Transport Scheme and the Severn Barrage, it is going to cost us more millions than we can easily afford in our present impoverished condition. The difficulty of finding the ready money seems to be considerable—as a private individual I may know of enterprises which would pay enormous dividends, but I may not have the cash handy, and may thus be prevented from constructing the machinery and necessary plant, and I may also not be in a position to borrow the necessary funds. Questions of high finance are altogether beyond me, but it is possible to point to our enormous indebtedness and ask if we are entitled to spend even such a trifle as £20,000,000 on an experiment. It is true that the spirit of the adventurer has made this country what it is, and that every new departure is fraught with danger, and the *possibility* of failure. This possibility of danger should not be allowed to damp our healthy optimism and cheerful cry of " excelsior." Still, there are occasions where it is necessary to call a halt and go slow. If my memory serves me, we had a few years ago a national debt of £700,000,000, and now, thanks to the war, we have to face the altogether ponderous sum of £8,000,000,000. Our rates and taxes are such as to well-nigh break our hearts, and, what is probably the very worst symptom of all, individual effort is being discouraged by legislation unfavourable to enterprise.

At the present moment there seems to be a very real and pressing danger of the establishing in this country a gigantic State monopoly, which may possibly be used for political purposes to the great disadvantage of the people. In my humble opinion any legislation which tends in the least degree to take the heart out of enterprising citizens should be discouraged by every possible means. Directly the feeling of security is diminished or undermined, there must be an attendant *lessening of the desire to acquire property of any kind*, and it is hard to conceive anything more likely to lead to decadence than this.

According to my present lights, Nationalization for this country means absolute control of the subject, who would no longer be a free agent. If it came, it would, indeed, be a sort of suspension of the Habeas Corpus Act. As Government controlled units we should have no scope, no power of exercising those adventurous instincts we have inherited from our forefathers, whether as explorers, inventors, or manufacturers—we should not, indeed, care to exert our faculties very severely since we should be unable to retain what we had earned by increased energy or industry.

Handing over to the State the management of our mines, railways, land, business, etc., etc., at present owned or controlled by individuals or companies, can only be effected by the instrumentality of vastly increased hoards of State servants or "permanent officials" who will often absorb more by their salaries than they can collect in the course of their duties. Is it in the least likely that we shall be better off in the hands of a greatly enlarged bureaucratic clique than we are at present?

Amongst the big works of the immediate future may be noted the huge proposed suspension bridge to span the Hudson River from Manhattan Island, on which New York is built, to Weehawken on the New Jersey shore. The river at the point selected is about three quarters of a mile wide, and the proportions of the structure completely dwarf our Forth Bridge. The extreme length of the new bridge is 8,300 feet. The New York end will begin in the 9th Avenue at 57th Street, close to the Central Park. The central span will be 1,000 yards, and it will be suspended between two steel towers, each 800 feet high, by steel cables, 5 feet thick. As is the case with its brother, the Brooklyn Bridge, there will be two decks, the lower of which will be 150 feet above the water; this lower deck will support eight railway lines, and the upper one six lines, as well as two broad roadways and two footpaths. A railway terminus will be built at the Manhattan end for all the lines now ending on the New Jersey shore. This gigantic bridge will easily hold the record for size and expense of construction. It will be the same length as the Forth Bridge, and the towers will be double the height and the cost is estimated at £40,000,000—some bridge, indeed! But, great as is the cost, a long-felt want will be supplied, since at present the only means of communication between New York and New Jersey is by the ferries and four tunnels, and these, having regard to the great increase in the population, are felt to be inadequate.

The "Piloting Cable" is, perhaps, one of the most promising of all the valuable inventions we have to record. It consists of a cable laid at the bottom of the sea in the true course of a vessel entering a harbour. This cable is capable of emitting, and does emit, magnetic waves which enable the officers on the ship to bring the vessel safely into port. According to the reports it is not surprising to learn that wide-world interest has been aroused by the working of the "radio" piloting cable, as it is called, now laid at the bottom of the channel at Porstmouth. By its means, fog-bound vessels are enable to steer an accurate course into the harbour. There is no connection between the ship and the cable other than the magnetic waves that are radiated from the cable. The cable is laid beneath the exact course to be followed by shipping, and its "free" end is out at sea. The Portsmouth cable is about twenty miles long, and the following short description has been furnished by experts:—"The high-frequency electric current in the cable emits a certain "note" in Morse code. The navigating officer on board the ship wears a set of ordinary wireless telephone receivers. These receivers are connected to a battery, a set of "amplifiers" similar to those used in wireless telephony, and two coils, the latter being hung over the side of the ship above the water-line—one on each side. On approaching the harbour the officer adjusts his earpieces and listens, first through one coil, and then the other for the "note" of the guiding cable. It may come to him through the right or "starboard" .coil, in which case he would know that his vessel was to the left of the cable. As soon as he hears the note equally loud through both "port" and "starboard" coils, he knows that his vessel is directly above the cable, and is able to feel his way along the correct channel."

We have had our stone age, our bronze age, our iron age, and now it seems as though the last few years had ushered in yet another age—the age of re-inforced concrete. From the smallest post to carry electric cables or wires for fencing to the biggest building we can erect, we see the steel skeleton surrounded with concrete. The material lends itself to very elegant designs and many graceful bridges have been built of this effective combination of materials. Enormously strong works can be carried out, but it is a *sine qua non* that everything from the design itself down to the last shovelful of concrete should be of the very best quality. There can be no such thing as a second quality in re-inforced concrete work ; one or two barrows of inferior stuff shovelled into the crown of an arch, for example, is sufficient to condemn the whole structure. The "jerry builder" should never be allowed to handle this material, and no contractor with easy ideas about quality should be entrusted with its manipulation.

So satisfactory were the results obtained through experiment and trials that barges first, and, later on, ships were constructed of the much admired material. Of course timber of some sort seems the natural material to use for floating vessels, but our naval architects soon showed us that steel was a more favourable and better substance for modern requirements—elastic, economical in space and enormously strong, it fulfilled all the required conditions. It always seemed to me that concrete is rather out of its element when floating on the top of the water in the form of a boat of any kind. There is this very serious objection, too: the sudden jars and jolts inseparable from stormy weather, and collisions, must inevitably try the integrity of the ferro-concrete beyond its capabilities. This is one objection, in my opinion, to its use in pier heads, where the piles may be subjected to sudden impact or pressure from heavy vessels coming alongside. To make my meaning clearer, re-inforced concrete is not a material which should be subjected to sudden and violent shocks. It is allright for retaining walls, piles, pillars, abutments, piers and the like, where steady resistance in tension or compression is required, but it seems to me to be out of place in shipbuilding.

Shipping losses round the British Isles were greater during the war than at any other time in our history. The Admiralty charts show the wrecks literally peppered, more particularly along the south and east coasts. On the dreaded Goodwin Sands we have the accumulation of centuries of disasters, and buried treasures, from the date of the Norman Conquest, lie around in profusion—all within the area of a few square miles. With regard to the value of the wrecks the cargoes of the old timber vessels have long ago perished with the exception of precious stones, gold and silver plate, doubloons and other coins. But with the ships sunk during the war the case is vastly different. In many instances the hulls and machinery are not seriously damaged by the submersion and the cargoes are far less damaged than many people suppose. If we take the number of war-sunk merchant vessels at 3,000, and put their *average* value at £100,000—we see that treasure to the extent of about £300,000,000 lies within easy distance of our shores. So near, and yet so far ! Up to now, we do not see our way to recovering this vast wealth which might be added to the circulating capital of the country could we but entice it from its watery prison.

With regard to the treasure buried in the Goodwin Sands, the story is told of an enthusiastic inventor who brooded deeply on the problem until his mind became unhinged. His idea was, so the story goes, to blow up the whole of the sand area with very high explosives, and then send divers down in every direction to hunt for the scattered treasure. Considering the jumble caused by the scattering and the cost of divers, this idea must be dismissed as impracticable. There are, however, two other ideas worthy of more serious consideration ; one is to run a tunnel from Deal to the Goodwins, and then, from the end of that tunnel branch off with smaller tunnels and search the sands in that way ; another idea is to build a sort of harbour on the sands themselves and work from that extemporised shelter.

It is said that both these scheme have been turned down by committees of experts to whom they have been presented. No doubt there are very grave obstacles, such as boring or tunnelling through quicksands, to say nothing of the difficulty of locating the wrecks in the first place. My own idea is roughly as follows. Having ascertained the probable position of the greater number of wrecks, I would sink a big floating concrete tower, similar to the Shoreham towers, in the most favourable position in Trinity Bay. This would be my base of operations, and from the base of this tower it should be possible to run tunnels in any direction. The next thing to consider would be the collection of reliable data, with respect to the actual location of as many ancient wrecks as possible. To get at this would take time, but I should go to work with the best boring plant procurable, and, by means of suitable augers by which I could secure specimens of the oak or teak or elm of which the vessels were built, valuable information could be obtained in this way. For instance, three lines of borings 100 feet apart and extending from north to south for the whole ten miles of the Goodwins, would probably reveal the presence of many old craft. The timbers of most of these vessels will be as good as when they sank for nearly all woods are preserved when constantly under water. Of course, when an auger came up with indications of wood, further borings would at once be made all around the locality, and the presence of the wreck, once ascertained could be accurately fixed. Proceeding in this way, and taking the borings every fifty feet, hardly a wreck could escape detection in the 200 feet belt. Over three thousand individual borings would be required to complete one such belt, but, by means of water jet appliances, the augers might be very rapidly sunk to the required depth. Having located a considerable number of wrecks, the next question would be to arrange for rapid tunnelling and upon the *possibility* and *cost* of this the success of the enterprise would mainly depend. It is known that many millions of pounds' worth of treasure are hidden beneath the Goodwins, but there is always the risk of not hitting off the best prize until a great deal of money has been expended on the work. We know that one ship with bullion to the extent of, say, £2,000,000 on board, will repay a good deal of outlay, but in an area of, say, twenty square miles, there are many chances of missing the mark. The problem of the Goodwins is a knotty one at best ; it is not exactly a " wild cat " scheme. but it comes under the heading of highly speculative adventure—possibly none the less fascinating for that—and I must say it is far more sound than many a mining proposition I have seen, because the treasure is really there, which is more than can be said of the gold in some of the mines !

The use of electro-magnets in conjunction with electric cranes is now very general in big scrap yards, and where the rapid shifting of heavy masses of iron or steel from one place to another is required.

Next to the electric crane itself the electro-magnet is, perhaps, the most valuable labour-aiding machine in use in many yards. It is a singularly handy appliance, it occupies very small space, considering its power, and saves time and unprofitable labour. The electro-magnet has been used with great success in clearing the bottoms of harbours from odd bits of iron, old anchors, etc., which might damage the bottoms of vessels when grounding on the mud or clay.

Possibly the usefulness of the electric magnet will be most strongly brought out as a means of assisting in the raising of vessels sent to the bottom during the war. An ingenious plan for combining submersible pontoons with these magnets has been recently put forward for bringing to the surface those wrecks which are lying at depths far beyond the reach of the diver operating under present salvage conditions. Roughly, the idea is to lower pontoons each side of a vessel, fasten them on to the sides of the vessel by means of powerful batteries of magnets attached to the pontoons, and then to force air at high pressure into the pontoons, which will thus be rendered buoyant, and rise to the surface of the water, bearing the wreck between them.

There is no doubt that there is a big field in which to operate, for there must be thousands of vessels lying in water varying in depth from 150 to 300 ft. which might be salved by means of suitable apparatus.

Optical Stress.

Amongst the many developments of applied science there is nothing of greater interest and importance in relation to the strength of materials than the employment of polarised light with transparent material under stress.

This discovery is due to Professor Coker, F.R.S., and has given us insight into the actual changes taking place in the interior of solid bodies under stress, which appears to be quite impossible of attainment in any other way. In the words of a recent article on the subject " the method of investigation in all cases is to determine the directions of the lines of principal stress by observation on a model of transparent material in a field of view illuminated by plane-polarised light." The difference of the principal stresses along the lines of principal stresses are measured by comparison with a standard tension member. The stress distribution throughout any plane member can be measured by this means to an accuracy of ± 3 per cent., and the results so obtained from transparent material such as celluloid can be appled to any homogeneous material such as steel or iron.

The coloured figures which have been reproduced in *Engineering* are probably familiar, and from a study of such diagrams, not merely the actual stresses but their distribution is determined for any possible kind of plane members, such as the ties or struts of a girder, or the stress at the point of application of the supports. But distribution of the stresses at the corners and angles of test pieces, and in riveted joints (results which have been obtained by these means) while confirming our views as to the evil effects of sharp corners, have in other cases entirely upset the generally accepted view as to what is happening in various parts of a framed structure when loaded. One of the remarkable results obtained is a complete explanation of why brittle materials fail near the enlarged ends ; and whereas in a ductile material stress distribution changes before fracture is reached and equalisation of stress takes place, in a brittle material out of alignment no such adjustment takes place, and a fracture near the ends is inevitable.

Mr. J. W. Wilson, F.S.E., M.Inst.C.E. (Past President), proposed a vote of thanks to the President for his address, which was seconded by Mr. W. Noble Twelvetrees, and carried by acclamation.

Monday, 7th, March, 1921.

SOME MODERN ENGINEERING PRACTICE IN AMERICA.

By Capt. Robert W. A. Brewer, A.M.I.C.E., M.I.A.E., F.S.E.

The Author of these sketches has recently returned to England after an absence of nearly six years. During the greater part of this time he has been engaged on Inspection duty for the Ministry of Munitions and has come into close contact with several new types of Engineering enterprise in his official capacity and otherwise.

Some of this work has been of such a specialised nature that it alone would be wearisome to the majority, it is thought that an omnibus Paper dealing with the leading features of several undertakings of widely diverging character would prove more generally useful and instructive.

Concrete as a constructive material is used to a very great extent in America, meaning the United States, the reason being not far to seek. The Members of the Society are fully aware of the extent of the Portland Cement industry in that country, Cement is easy to transport, it can be handled in small units, meaning bags, the sand and aggregate can usually be obtained locally, but, perhaps, the most important feature is that concrete construction as carried out in the States requires very little skilled labour. Practically all the mixing is done by machine, either operated by electric motors or petrol engines, and in all works of any magnitude the distribution of the mix is accomplished by conveyor or chute.

A large proportion of the labour is of Italian or Slavic birth, many do not understand the English tongue, so that constructional work has to be of such a character that mechanical means must be relied upon to a very great extent. Much constructional work is carried on in regions remote from workshops, hand forming of parts must, therefore, be possible, also the shortage of other forms of building material during the War has made Ferro Concrete a most valuable and useful substance.

In California, where the Author has been occupied for several years, one cannot fail to notice the large number of concrete roads; this material has been found to stand the climatic conditions better than any other, the surface is left comparatively rough, so that it gives a fair foothold for horses, it does not become slippery for motor cars, it stands the great heat of the Summer sun, and only cracks a very little in Winter.

The eight half-tone blocks have been kindly lent by the Editor of the *Journal of Electricity*.

In the desire for long mileage of good roads the Californians have cut down the thickness of the material to a minimum, they own that their roads will not carry heavy traffic and would be useless for military purposes. This, however, is not the object, the large agricultural community requires some cheap and rapid method of disposing of their produce. Since the advent of good concrete roads, the main industry of California has undergone a revolution, farmers no longer are required to live on their ranches, produce is quickly and cheaply carried from the fields direct to the canneries on pneumatic-tyred lorries. This rapid hauling is the salvation of the perishable fruit trade.

A thin crust of about 3 or 4 in. of cement concrete is practically all that is employed, the road fillings and bridges are not covered till several months or a year after the main work is completed, giving the new soil time to pack. Generally only a narrow portion of the centre of the road is concreted at first, sometimes only sufficient width for one vehicle, turnouts being provided at intervals. The author has not come across reinforced concrete road construction of which he is aware, but he has examined the designs of an automatic machine for the continuous construction of such roads ; the principal feature involved is the use of material containing very little water, no side shuttering, but considerable tamping. The reinforcement is unwound from a roller on the machine which travels continually at a slow speed. A machine will lay a road at several times the speed of hand construction besides requiring only a few men to operate it.

A passing note on the construction of concrete ships will be of interest, several of which were examined by the Author, they were erected broadside on to the water's edge, the idea being that only the shuttering on the water side would have to be removed after the work was completed. The in-shore shuttering was then immediately ready, except for the lining, to commence work on the next ship. The various aggregates proposed to be used were examined in the testing works, the burnt brick eventually adopted to a great extent, appeared to be the most suitable ; it was light and showed well on test.

There appeared to be some difficulty in ramming the very narrow boxes into which the shuttering was divided, the mix was placed in position in small quantities, and the board work vibrated with air hammers. The method adopted did not seem to compare well with the very modern ones used in other types of concrete work.

Bridges of concrete are numerous, some fine examples are seen in quite remote parts of the country, but, as may be expected in any new country, the approaches are often not good. Sometimes a lack of proper foundation and a flood cause failure in an otherwise good structure.

Perhaps the most interesting concrete work in California is the oil reservoir, the problem of containing vast supplies of crude oil in somewhat remote districts not only is peculiar to California, but also to the British Empire. During the War the absence of metal plates and the difficulty of transport made it essential that reservoirs be constructed of other material.

The possibility of using a simple type of construction in concrete had not only been faced in California, but it had been met successfully. The following description of these reservoirs will be of interest.

Oil Storage Tanks of Concrete.

The choice of a suitable site for a reservoir is one of the most important factors governing the success of the undertaking, the soil should be preferably a sandy clay in which clay predominates, the site should be well drained, and care taken that there should be no chance of the percolation of surface waters nor seepage from adjacent streams ; this precaution is necessary in order to prevent the formation of a hydrostatic head behind the concrete lining. If sand pockets are encountered in the excavation, these should be removed for a distance of at least 3 ft. or more below the finished work, and the space filled in with thin layers of selected earth, each layer properly tamped.

The earthwork forms the main foundation of these reservoirs and great care must be expended upon it in order that the subsequent lining should be adequately supported at all points at all times. The soil should be such that it will pack well, and during the process of excavation and packing, which occur simultaneously, the correct routine must be adhered to.

Experience has shown that horses are preferable to mechanical means for removing the soil, the reason being that the intensity of pressure upon a horse's hoof is greater than that upon the wheels of a power machine.

The main dimensions of a standard reservoir of 750,000 barrels capacity are as follows :—

Inside diameter at top ...	488 ft. 0 in.
Inside diameter at bottom...	437 ft. 6 in.
Maximum depth approx. ...	26 ft. 0 in.
Slope of embankment inside	1 horizontal to 1 vertical.
Slope of embankment outside	2 horizontal to 1 vertical
Slope of embankment top ...	24 horizontal to 1 vertical.
Width of embankment on top	15 ft. 0 in.
Area of bottom	150,330 sq. ft.
Area of sides	53,200 sq. ft.

The reservoirs are circular in plan.

Method of Excavation.—The first work consists of stripping the entire area, both the portion to be cut and that to be covered, of all vegetable matter and top soil. This stripping must be to a depth of at least 8 in. below the surface. This material must be moved away from the site, ditches are then dug for two 12 in. oil mains and one 8 in. water drain.

The area below the embankments is then prepared to receive material by being plowed up and harrowed and moistened with water. The general work of scraping out the bottom and filling on to the embankments now proceeds, this is carried out, preferably, by what are known as Fresno scrapers. These scrapers are horse-drawn scoops which are worked in a circular course, about 8 teams working simultaneously on one job. The soil is continuously watered, is placed on the embankment in layers not more than 3 in. thick, again watered, and spread if necessary. The teams walk continually over the material which has previously been dumped, and the tamping of the horses is further supplemented by a petrolithic roller passing round the top of the dump.

When two of these rollers are used they should be of the 4 horse type and make 10 complete circuits of the reservoir per hour. The petrolithic roller is interesting, consisting of a roller fitted with numerous projections resembling a sheep's foot, as this form has proved most efficient for the purpose. Continuous watering takes place, the water being brought to the job in a ring water main surrounding the outer toe of the embankment at a distance of 20 ft. The scrapers work up one runway, along the top of the embankment for a distance of about 100 ft. and descend another runway.

The excavation of the bottom of the reservoir is carried to a depth of about 1 ft. below the finished level of the concrete, the excavation for the inner slope of the embankment is carried back the width of a scraper beyond the finished line and then built up with material taken from the bottom, properly tamped as in the walls.

By these means all the backing of soil is made homogeneous and sound, the material when fully excavated must be left for three days before being trimmed.

The excavation now being finished, the inner slope of the embankment is trimmed off to proper grade and size, the material removed supplies the fill for the bottom.

About a foot thickness or more has to be removed; this is done in the following manner :—Grade stakes are set in radial lines at the top and inner toe of the slope, at approximately 10 ft. apart around the circumference of the reservoir and trenches about 6 in. wide are then dug to grade. Slope level boards of 2 in. by 4 in. are used and the trimming between these boards is then done by hand or with a special scraper drawn by horses which walk along the top of the embankment and pull the drag line via two blocks. The material is spread over the bottom and rolled in thin layers by rollers of not less than 5 tons weight, the bottom having been previously roughened by plowing and harrowing. The outer slope is formed in the same manner as the inner slope, and when finished is thoroughly sprinkled with oil to prevent the washing of the earth by rain and to retard the growth of weeds or grass which would form a fire risk in dry weather.

Passing on from the small details and also the roof which vary in different jobs, the concrete will next be considered.

Concrete Work.—The sides and bottom of these works are covered with a layer of reinforced concrete 3 in. thick; no particular specification is insisted upon for the Portland cement except that it shall be of a good grade. The rock used as aggregate is ½ in., *i.e.*, passing a ½ in. mesh and retained on a ¼ in. mesh: also 1 in. rock, passing a 1 in. mesh and retained on a ½ in. mesh.

The reinforcing material found most satisfactory for this work is a welded metal fabric having 4 in. by 4 in. mesh, of number 6 gauge wires both ways. This fabric is made in rolls 86 in. wide and 240 ft. long.

The fabric is laid along the floor across the foundations of the roofing piers, the longitudinal splices are lapped one mesh and wired together with 16 gauge annealed iron wire. Transverse splices lap 24 in., the reinforcement is ready on the floor to be raised into the centre of the mass as the concrete is poured.

The proportions of the mix vary slightly in different jobs but the following is an example:—The bottom and roof piers: one part cement, two and a half parts sand, two parts of ½ in. crushed rock, two and a half parts of 1 in. crushed rock.

The concrete for the sides is:—One part cement, Two and a half parts sand, two parts ½ in. crushed rock.

The mix is made with the minimum possible amount of water and in batch mixers, a layer of 1½in. thick is poured on top of the reinforcement which is drawn up through the concrete, and allowed to rest on top of it. At once the next layer of concrete is poured to bring the thickness up to 3 in., and the surface tamped with wooden tampers and finished smooth with the trowel.

It is absolutely essential that the finished concrete be dense and have a dense close grained glazed surface. The whole crux of the problem of watertightness lays in keeping all material except cement from the surface, thorough tamping must leave a finished surface upon which no particle of aggregate can be seen. Further, the work must be so solid that cracks will not appear at any time.

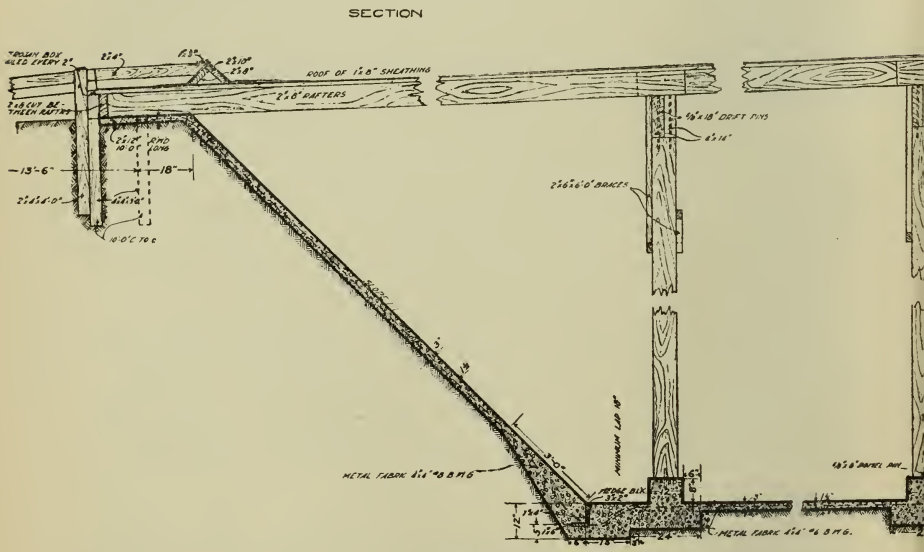
When proper care is taken to make a dense and compact lining, and all aggregate is well below the surface, an oil tight structure can be made; after 5 years there has been no evidence of penetration, the oil when wiped off leaves a clean surface on the concrete.

Owing to the small variations in temperature in an oil reservoir, not more than a total of 20° Fah., the use of expansion joints has been found undesirable. In some cases where they were built, they have subsequently been removed as they were a leakage risk.

One circular joint is, however, used at the bottom of the slope; in this is placed a wood block of 3 in. by 2 in. resting on a 1 in. by 6 in., there being a local thickening of the concrete at this region to 12 in.

Any small shrinkage cracks are filled with grouting and a cement wash is given to the whole of the interior after 20 days standing.

Several reservoirs of one million barrels' capacity have been built in California, but this is about the maximum economic size for construction with Fresno scrapers, as the length of economic haul is limited.



DETAILS OF ROOF FRAMING AND CONCRETE LINING OF 750,000-BARREL RESERVOIR

Fig. 1.

The cost of two of the 750,000 barrel size, built at Bakersfield, California, in the Winter and Spring of 1913-1914, is given as follows :—

On a basis of 11 cents a barrel capacity.

Cost of earthwork, cents	3·5
Cost of roof, cents	3·0
Concrete lining, cents	4·5
	11·0

	$
Earthwork :—	
Excavating for embankment, per yd.	0·22
Lining inner slopes, per yd.	0·51
Finishing floor, per sq. ft.	0·005
Excavating pier footings, trenches, per yd.	0·70
Trimming slopes, per sq. ft.	0·012
Concrete lining :—	
Hauling cement, per ton, ½ mile	0·54
Hauling sand, 2 miles, per yd.	0·86
Hauling rock from cars, per yd.	0·50
Laying reinforcement on slope, per square	0·16
Ditto on floor, per square	0·08
Pouring concrete piers, per yd.	4·63
Pouring concrete floor, per yd.	2·51
Pouring concrete slope, per yd.	3·46

The last three items include the cost of rock at $1·60 per ton, but not the cost of sand and cement.

The basis is upon a day worked of 9 hours.

	$ a day.
Wages of labourers	2·50
Wages of carpenters	3·50
Wages of concrete labourers	2·75
Wages of concrete finishers	4·50
Wages of foremen	6·00

An unlined earthen reservoir of the same type of construction of roof would cost 7½ to 9 cents per barrel. The situation of these works was half a mile from the railway. The roof work in this instance was of wood.

The cost of a concrete reservoir can scarcely be compared fairly with that of a steel tank, but it may be stated in passing that a 55,000 barrel steel tank could have been built in August, 1914, at a cost of 30 to 32 cents a barrel depending on the location.

In 1917 this cost would have been 42 to 45 cents a barrel, with steel roof.

Wooden roofed tanks were being erected at the same periods at 25 to 27 cents a barrel and 37 to 40 cents a barrel respectively.

The Manufacture of a Delicate Electrical Apparatus.

The second section of this paper deals with a specialised product which has been largely used during recent years and particularly in military operations.

The apparatus referred to is generally known as the Vacuum Valve and the reason why it is discussed here is that the Author has been intimately connected with its manufacture in America. As there may be some Members present who are not familiar with this device, a few general observations on the functions of the Valve will be of value.

The valve is based on the original Fleming two element thermionic detector first made by Prof. J. A. Fleming in 1904 from an incandescent lamp by surrounding the filament with a metal cylinder. In 1907, Dr. Lee de Forest, in America introduced a third element in the form of a grid between the plate and the filament, both of these inventions are held to be fundamental.

When used as an amplifier of radio signals its function is to render audible such vibrations as would otherwise not be discernible. This type of radio signal may be beyond audibility either by reason of its weakness or on account of interference or jamming. There is no particular merit in an amplifier producing a superlative noise, which only militates against the life and usefulness of the apparatus employed.

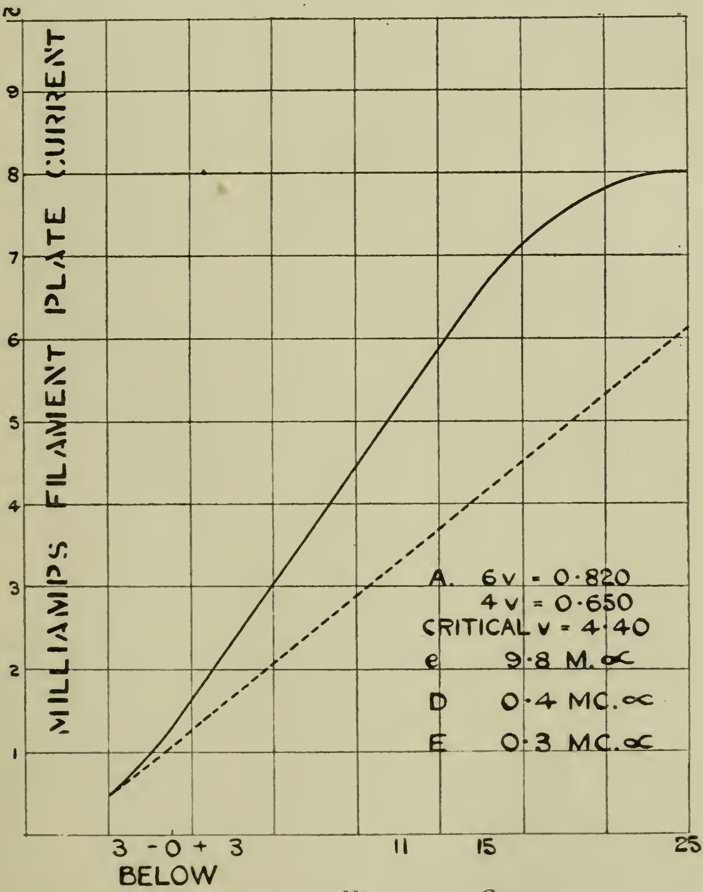
The thermionic principle upon which the valve operates is based upon the emission from a hot cathode of negative electrons, these flow to the anode or plate. The quantity of the flow is governed by the temperature of the cathode when its dimensions are fixed. The emission of electrons necessitates the absorption of kinetic energy which has to be supplied by the battery in circuit with the cathode.

The original Fleming valve comprised an anode upon which a positive potential was impressed by means of a second battery, the circuit being completed through the valve to the negative end of the filament. The anode when positively charged attracts the negative electrons emitted from the hot cathode, the electronic flow through the valve bears a relation therefore to the positive potential of the anode. As this is increased, so will the electronic flow increase until saturation occurs.

The capacity of a valve which is purely electronic depends upon the two factors mentioned. Distinct from the purely electronic valve or as it is termed the " hard " valve is the gas or " ionizing " valve which is an older type. Professor Fleming, however, states that some of his earlier valves were exhausted by Professor Dewar's method in which the vacuum is obtained by cocoanut charcoal cooled in liquid air; this gives the highest known vacua. It is assumed, however, that these were only experimental valves.

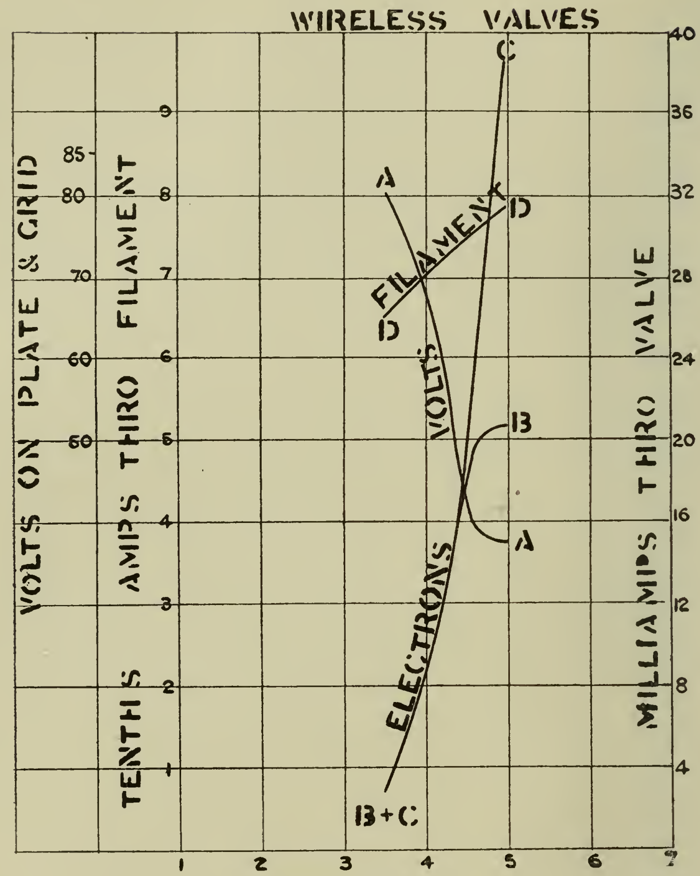
If gas is present to the extent that 1/100,000th of a mm. of mercury pressure exists, ionization of this gas takes place, the molecules of gas come in contact with the positively charged anode and themselves assume a positive charge and are consequently repelled from the anode and bombard the cathode, rapidly to cause the destruction of the latter. The presence of gases in a vacuum valve also causes the formation of negative electrons so that on test a greater current flow is shown but its behaviour is very erratic. For this reason a hard valve is preferred in practice in spite of the difficulty of removing the occluded gases from the metal parts and the glass bulb.

The third element or "grid" is interposed to control the current flow through the valve by variation of its potential, its presence introduces great possibilities, as slight variations of voltage impressed upon it can either check the current flow



Voltage of Grid.

Fig. 2.—Flow of Current Controlled by Grid (see p. 49).



Filament Voltage.

Fig. 3.—Electronic Flow on Tests (see p. 51).

entirely, when acting in opposition, or increase the flow many fold when a positive potential is impressed upon it. (Fig. 2.)

The sizes and disposition of all the elements in a valve are worked out with the greatest degree of accuracy, the satisfactory operation in service depends upon accurate manufacture, so that the problem is quantity production of exactly similar apparatus within very narrow limits. Further the fact must be borne in mind that the majority of the faults liable to creep into such manufacture can only be detected when the article is practically completed and the electrical tests are applied. By this time, if a fault has developed in a jig or a process, probably a great number of pieces are on the way having the same fault.

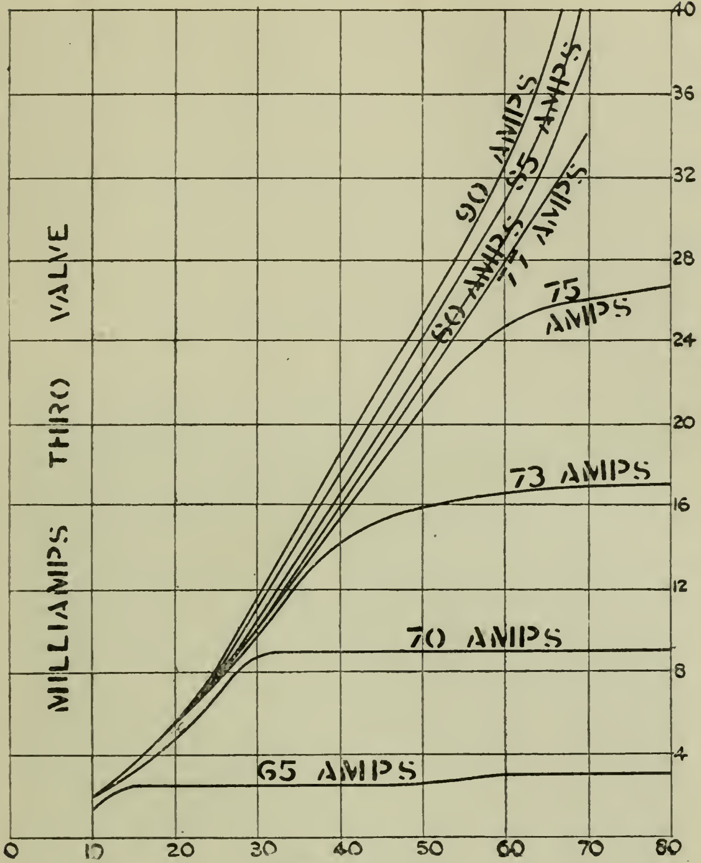


Plate Voltage.

Fig. 4.—Emission of Electrons (see p. 52).

The author was largely instrumental in bringing into operation a method of manufacture of this very delicate piece of electrical apparatus on which a start was made in May, 1918. The work was carried out on the Pacific coast, 3,000 miles away from the source of supply of the essential raw materials. The available skilled staff comprised one mechanic, one glass blower, one pump operator. In addition, was a highly skilled radio operator, but the rest of the employees had to be picked up from all sorts of occupations; the majority of them were taught their respective duties by the author. All of them were women and girls, including the testing staff, and they showed remarkable adaptability to this new and in some cases difficult work. Every valve made was tested and a large number of curves was made, some of which accompany this paper. At the time of maximum output about 70 hands were employed and the production was at the rate of 1,000 good valves a day. One remarkable point about this method was the comparatively small percentage of wasters as compared with the reported wastage in other factories. This work was severely handicapped from the start as no drawings were supplied showing the disposition of the electrodes, the specification did not state this and it was found that after the first shipment had been made, the valves in production were not to the intended form being vertically mounted instead of horizontal.

They were accepted in the vertical form for receiving valves, a change being made in the transmitting type.

Special apparatus had to be designed and made in the factory before the work could be commenced, each appliance had to be automatic as far as possible, at any rate the human element had to be eliminated as far as practicable. A description of some of the leading operations will be of interest.

Glass Bulbs.—These were received from the glass works in a partially formed state, the stems about 2 in. too long. After washing in an acid bath they had to be shortened. The first method tried by notching and fracturing with a hot wire resulted in too much waste. The operation on the glass was changed and carried out as follows :—

Tubulating.—Each bulb in turn is placed in a cradle with the stem upwards and, by means of a flexible connection, a small air pressure is introduced to the centre of the bulb. A small gas flame impinges upon the bulb where the tubulation occurs and as soon as the glass comes to a molten state the air pressure blows out a small pip and the bulb in this state is at once transferred to the tubulating machine which is worked by the same operator. The bulb is them inverted so that the stem is downwards. Immediately above it a tube is placed in a grip, this action being simultaneous with the placing of the original bulb under the operation previously described so that the tube is now hot and the flame which has softened the end of the tube now suffices to fuse the tube to the bulb, these two parts being brought mechanically into contact by an operating lever on the machine. The next movement withdraws the parts so that a neck is drawn on to the tube. (Fig. 5.)

Cutting-off to Length.—The bulb now passes to a cradle below which a number of gas jets impinge on the bulb stem at a suitable distance below the bulb. This ring of flame brings the glass to a molten state and the weight of the surplus metal draws the tube down till it falls off. Immediately the operator picks up the bulb and blows out the molten end into a small thin bulb which is immediately fractured, thus giving a bell-mouth to the bulb stem. This bell-mouth, in addition to being truly central, permits an entry for the flange on the glass stem carrying the elements, which stem is immediately fused into the bulb on a special form of lamp machine with four heads.

Fusing in the Elements.—(Fig. 5.) The four-headed machine has three of its heads provided, at the stopping points, with rings of gas flames turned to different heights, the first giving a gentle heat, the intensity of the heat increasing up to the third position where the actual fusion occurs. The machine is loaded by placing a glass stem carrying the elements into the carrier with the elements upwards. Over the top of this, the glass globe is fitted, also in a carrier, so that the globe and the elements rotate when the machine passes to the positions where the flames occur. This rotation is caused by friction wheels which come into contact with the carrier as soon as it reaches one of the stopping points where the flames are located. Immediately fusion occurs, the valve is taken from the carrier and centralized with a stick placed up the stem where the wires go through. It must be noted that the wire carrying stem is placed on the carrier by first threading the wires downwards through a hole provided for the purpose.

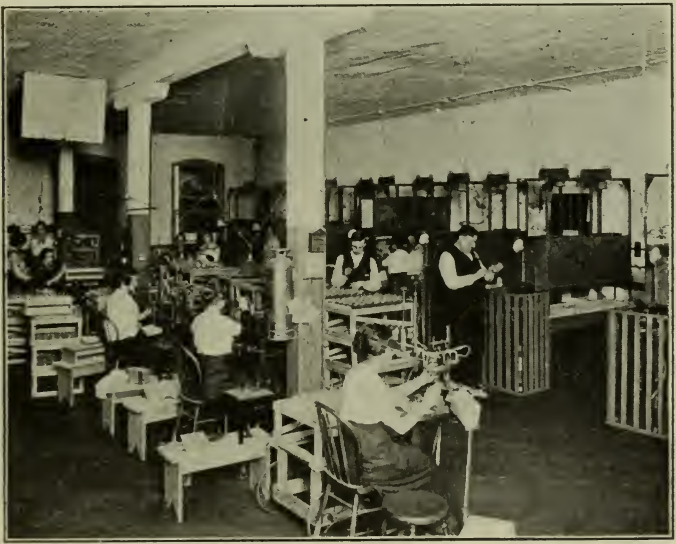


Fig. 5.

Glass Fusing Machines in Foreground. Evacuating Ovens in Background.

Construction of the Elements.

Sealing in the Wires.—The four wires are sealed into the glass stems in a somewhat similar machine, the four wires having previously been fanned by hand and placed within the glass tube with the nickel ends upwards and located against a gauge point so that the platinum in each wire will come in line and at the proper position in the glass. Each of these carriers has a pair of finger clips fixed below it operated by a lever so that when the unit arrives at the third position and the glass is at the point of fusion the finger clips come up and nip the glass tube, thus sealing in the wires.

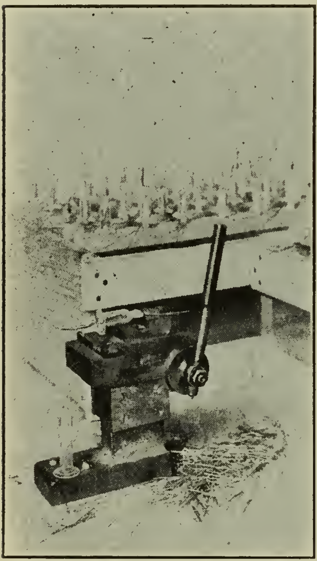


Fig. 6.
Machine for Forming the Support Wires.

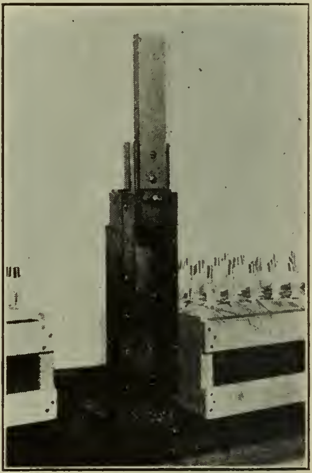


Fig. 7.
Drop Hammer for Forming Spring Tension on Filament Supporting Wire.

Wire Forming.—(Fig. 6.) The tubes now carrying four wires, next have the nickel ends straightened by hand. They then have each of the four wires passed horizontally into a steel die; first the wire attached to the lower end of the filament is cut off to form the short hook and is turned over at right angles. This forms the gauge point for locating the wires for cutting off their finished length. The tube is held square by the die and the surplus wire cut off by scissors up against the face of the die. Next, the long wire which eventually holds the upper end of the filament is bent out of the way so that the welding

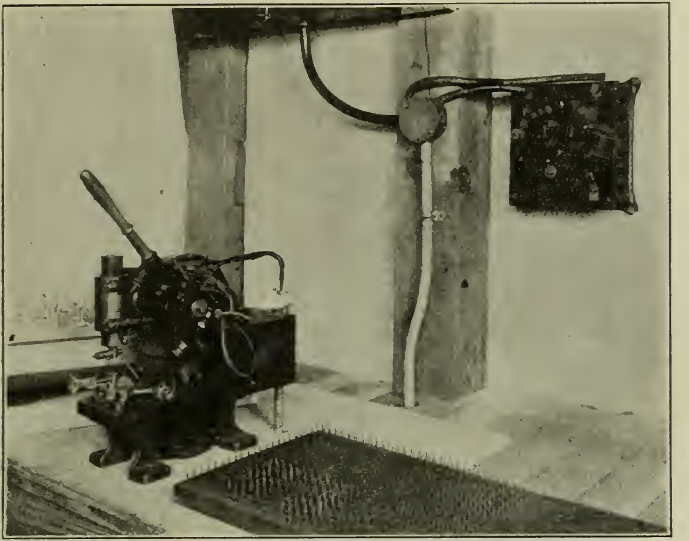


Fig. 8.

An Electric Welder for Fixing Anodes and Grids shown with a Tray of Grids.

operations can be accomplished on the other two elements. This wire is then locally flattened in the drop hammer. (Fig. 7.) This unit now goes to the grid welding machine (Fig. 8), which is a spot welder wound with 200 volts on the primary.

The grid is a nickel wire 0·25 mm. diameter formed into a series of 11 coils of 4·25 mm. internal diameter, the coils are spot welded to a nickel support wire at three places. The grid is threaded on to a small mandrel having a very slight flat on the top. At the remote end of the mandrel there is a small shoulder against which the grid supporting wire is located. The grid at this time is slightly less in over-all length than the finished length so that it is placed by hand with one end level with the point of the mandrel nearest to the operator, and when the lever is pulled down to bring the welding points in contact it welds the penultimate coil in place, the unit is then drawn forward on the mandrel, the end coil placed level with the end of the supporting wire and the penultimate coil at the top fixed by a spot weld. One additional spot weld is placed in the middle of the grid. This method insures the exact length and location of the grid.

Anode Fixing.—A similar system of welding is employed for the anode cylinders but in this case the mandrel is hollow and the grid and its supporting wire are placed inside the hollow copper mandrel ; the anode being first slipped on to the mandrel against a shoulder which locates its position and that of the supporting wire. The anode is then spot-welded in two places but after each of the welding operations the element welded is straightened up by hand, as the support is liable to be distorted by the heat.

The anode is a nickel sheet bent into a cylinder of 10 mm. external diameter by 15·2 mm. long and 0·2 mm. thick. It is supported in position by a small nickel angle piece to which it is spot welded; the angle is welded to a platinum wire for sealing into the glass bulb and to a copper connecting wire. More than a million welds were made in the course of this work.

Filament Fixing.—The filament consists of a crimped tungsten-thorium alloy wire 23 mm. long between supports and of such an actual length that the current passing under a PD of 6 volts at its terminals is 0·84 amps plus or minus 0·035 amps. The filament crimping machine gives a continuous crimp to the tungsten wire which is fed to the machine in one long length and is pushed through the centre of the grid by hand. The element is located in a horizontal position, a small steel cradle holds the anode which is clamped down by a hinged upper half, the unit being located against a shoulder. (Fig. 9.) The long wire holding the upper end of the filament is now formed round the base of this apparatus, being pressed by a lever against a forming surface so that it finally comes into its correct position, the end being concentric with the other two elements. In the position in which the unit now lies the short hooked end of one wire and the long hooked end of the other wire are now lying on the centres of two small anvils, and above them are two punches located with their centres the exact distance apart to give the necessary active length to the filament. The filament is threaded through the centre of the grid and first the short hook is riveted to one end of the filament; the latter is then held across the long hook with no tension and the other junction made. A few small blows with the hammer

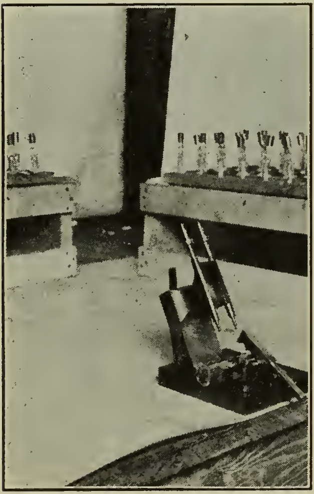


Fig. 9.

Punches for Fixing the Filament. Elements in the Background.

on the end of a punch is sufficient to drive the hard tungsten into the softer nickel and makes a positively secure joint.

The grid forming machine (Fig. 10), consists of three rotating spindles, parallel, driven at the same speed, one carrying the hardened steel roller having two grooves upon it giving the distance of the pitch of the grid ; one spindle carrying one roller with a single groove, which rollers press the wire on to the rotating mandrel giving the inside diameter to the grid ; these spindles are geared together and motor-driven and produce spirals 2 ft. long. A spiral is cut up in sections by placing the requisite number of turns in the teeth of a comb fitted to a steel block with a stop at one end, each turn entering between two teeth, the final length being cut off by scissors. The anodes are formed from nickel strip cut off in flat plates by dies and passed through a small rolling mill giving the cylindrical formation. The nickel supporting wires also pass between a rolling mill, one roller of which is serrated ; this mill is operated by hand and cuts the wires off to a convenient length. The glass tubes carrying the wires are cut off to short lengths by a V-shaped emery wheel ; each one is then separately placed in the hollow spindle of a small lathe, a blow-pipe flame plays upon the protruding end which in a semi-fused state forms a flange, being assisted by a hand tool.

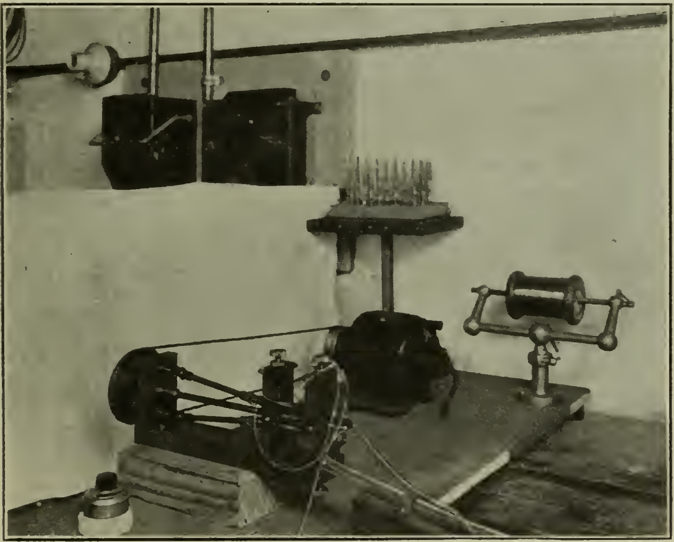


Fig. 10.—Machine for Coiling the Grid in a Continuous Spiral.

Evacuation by Langmuir Pumps.—(Fig. 5.) There are ten ovens, each of which will carry about fifty valves, but about forty at a time are sealed on to the glass manifolds. Along the bottom of the oven are two rows of gas jets which keep the temperature about 650° F., during the time of the evacuation. Where the glass tube leaves the oven, at the end where the pump is fixed it turns into a downward leg into which the necessary driers can be placed. The pumps are of a mechanical and mercury vapour type ; each one having a duplex head in place of the single head usually provided, and the pumping operation has been reduced from about four hours to about one and one-half hours by reason of a special treatment which has been arrived at as a result of considerable experimental work. Although it has been possible to obtain the prescribed blue glow test by direct pumping and freezing, the time involved militated against this method as a commercial one and the valves as treated comply with the tests. Incidentally, a pressure of over 1,000 volts can be applied to the anode, but this pressure may be modified as advisability dictates. After the valves have been removed from the ovens they are subjected to a special treatment to ensure the absence of blue glow, indicating

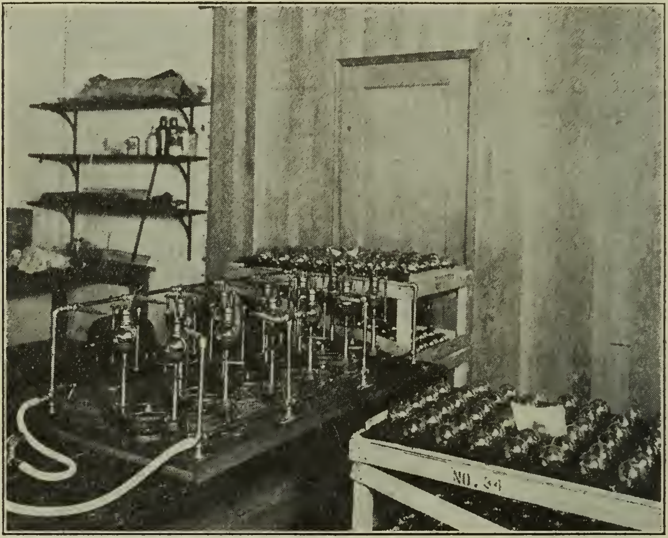


Fig. 11.

Machine for Fixing the Bases.

Fig. 12.
PART OF THE TESTING APPARATUS.

the nature of the extent of the vacuum. This is immediately followed by a test for vacuum consisting of a high potential impress on the anode ; during this test the anode becomes white hot due to the electrical bombardment. Having passed this test the valves are based (Fig. 11), and the wires soldered on the the contacts. The final electrical tests then follow. (Fig. 12.)

Most of these tests are too specialised for this Paper, but it is necessary that when the proper voltages are applied to the plate and filament, regular increments of grid potential will cause the values of valve current to fall on a straight line curve within the limits of the capacity of the valve. All the valves tested showed a greater value than the specified minimum ; a typical curve is shown in Fig. 2. Several tests were made with valves specially made with errors of dimensions and others with faulty placement of the elements, some test results of these are shown in Table III. The mechanical strain on the elements when undergoing severe test was noticed in the straining of the filament, and in some cases it was actually drawn into contact with the grid, thus causing failure of the valve. One of the fine tests, Table I, was so delicate that the valve had to operate with a fraction of a millionth of an ampere. In spite of the delicacy of the device, a type of packing was designed which ensured safety of transport; one of these is shown to the meeting in which the author has carried a valve for two years about the world, the valve was tried by him on actual service on the voyage from America and found to be in perfect condition.

The three elements are arranged concentrically, and the characteristic curve shows the behaviour of the valve under the following tests, with the object of certifying the correctness of the disposition of the elements within the valve.

A PD of 80 volts is impressed upon the anode with respect to the negative end of the filament, and a local current is passed through the filament at a voltage of 4 across its terminals. The grid is now subjected to varying voltages between minus 3 and plus 25, and the filament to plate current is read off and plotted as in Fig. 2. These values are required to show a straight line between the aforementioned limits and to have an increment of a minimum of 0·2 milliamperes per 1 volt of grid PD variation.

The characteristic curve of a valve of the receiving type according to Langmuir's formula should show :—

Plate current $= A (V_p + K V_g)^{2/3}$

A being a constant.

K is a constant depending upon the linear dimensions of the elements and their arrangement.

V_p and V_g are the potentials of the Plate and Grid.

The curve Fig. 2 passes through observed points at intervals of 1 or 2 grid volts which are located on the abscissæ, whilst the ordinates indicate the value of the electronic flow through the valve in milliamperes of filament-plate current.

When no voltage is impressed on the grid the current is 1·3 milliamperes, and this is reduced to 0·5 when a negative charge of 3 volts is placed upon the grid. The form of the curve indicates that 4 volts negative applied to the grid would stop the current flow by building up a space charge of sufficient magnitude for that purpose.

Under these conditions the valve will be inoperative until the negative potential of the grid is eliminated. The dotted line starting from the lowest observed reading gives the locus of the curve of the desired minimum current flow having an increment of 0·2 milliamperes per one volt rise of grid PD. The actual tests all show that the valve in operation always exceeds this increment and that the curve is practically a straight line.

TABLE I.—This test shows that the grid controls the valve action in a perfectly regular manner.

The emission of electrons from a heated filament has a critical point where a very slight increase in the temperature of the filament will cause a great increase in the emission. This will be observed in the curves. (Fig. 4.)

The most useful test of the correctness of manufacture of a receiving valve is that for the filament-plate current when the grid is externally connected to the plate and a voltage impressed upon them with respect to the negative end of the filament.

Fig. 3 shows results of such a test graphically, but the plate voltage has been permitted to drop as the valve current increased. This drop is due to the decrease of internal resistance of the valve caused by an increase of the bombardment of negative electrons emitted by the hot cathode. The method of making this test is to start the filament voltage at a point where the valve current begins to flow appreciably, in this instance 3·5 volts on the filament produce 0·65 amperes through it and cause a valve current of 3·0 milliamperes when 80 volts are impressed on the grid and plate shorted together.

TABLE I.

DISPOSITION OF ELECTRODES.

Valve Number ...	7	8	9	10	11	12
Filament Voltage.	Ampères through Filament.					
6·0	0·840	0·840	0·825	0·875	0·845	0·820
4·0	0·670	0·675	0·660	0·690	0·680	0·650
Critical voltage ...	4·3	4·4	4·3	4·3	4·25	4·40
Voltage on Grid.	Milliampères Plate Current.					
−3	1·0	0·7	0·9	0·9	0·5	0·5
0	1·8	1·5	1·6	1·9	1·2	1·3
3	3·0	2·5	3·0	3·1	2·1	2·3
11	5·7	5·7	6·4	7·3	4·9	5·1
15	7·2	7·3	7·4	8·5	6·5	6·6
25	8·2	8·3	8·3	9·0	8·4	8·0
Test C.	Milliamps. Current between Filament and Electrodes.					
Grid and Plate shorted 80 V. impressed ...	10·6	10·5	10·0	11·4	10·1	9·8
Backlash.	Micro Amps. negative current grid to Filament.					
160 V. on anode 4 V. on filament 2 V. negative on grid	0·4	0·4	0·4	0·8	0·3	0·4
	Micro Amps. positive current to grid.					
As above with battery removed	0·2	0·3	0·3	1·0	0·3	0·3

The rheostat in the plate circuit has remained untouched as the filament voltage was increased, so that at 4 volts and 0·70 amperes in the filament circuit the electronic flow has reached 8·0 milliamperes, and the plate voltage has dropped to 68. These observations were discontinued at the point where the filament voltage was 5·0, the current 0·78 amps., and the valve current 20 milliamperes with 38 volts impressed on the anode. The curve Fig. 3 shows the fall of plate voltage A.A. accompanying a rise of filament voltage D.D., and an electronic flow B.B. when the grid was disconnected and 80 volts initially impressed on the anode. Also the curve C.C. shows the increased electronic flow when the plate voltage was maintained at 80 volts.

TABLE II.

TABLE SHOWING FLOW OF CURRENT THROUGH VALVES WITH 80 VOLTS IMPRESSED. GRID AND PLATE SHORTED.

	Short Grid.		Long Grid.		Grid out of centre, coils uneven.		Long Filament.	
Filament Volts.	Milli-amps.	Fila-ment Amps.	Milli-amps.	Fila-ment Amps.	Milli-amps.	Fila-ment Amps.	Milli-amps.	Fila-ment Amps.
3·6	1·0	·630	3·0	·658	2·0	·578	—	—
3·7	—	—	3·8	·667	—	—	—	—
3·8	1·5	·652	4·5	·675	3·2	·595	—	—
4·0	2·7	·670	7·0	·695	4·8	·613	—	—
4·2	4·5	·685	9·8	·715	6·8	·630	—	—
4·4	7·6	·705	13·5	·730	9·5	·645	—	—
4·5	9·5	·710	16·0	·738	11·0	·652	—	—
4·6	11·0	·718	18·7	·745	—	—	—	—
4·7	13·6	·728	21·5	·755	14·5	·665	—	—
4·8	16·4	·735	25·5	·763	17·8	·675	2·5	·494
4·9	18·8	·742	28·8	·770	20·5	·680	3·4	·500
5·0	24·0	·750	33·4	·778	23·0	·688	4·5	·508
5·1	—	—	—	—	—	—	5·2	·512
5·2	—	—	—	—	—	—	6·7	·518
5·3	—	—	—	—	—	—	8·0	·520
5·4	—	—	—	—	—	—	9·8	·524
5·5	—	—	—	—	—	—	12·0	·528

The curve Fig. 4 is interesting as being typical of the electronic flow through a valve of two elements ; several observations from a hard valve are here plotted, the grid being disconnected and a definite current passed through the filament whilst the plate voltage was increased step by step. The test was then repeated with an increased current through the filament and so on at varying filament current values between 0·65 amperes and 0·90 amperes.

The plate voltages adopted in these tests started at 10 volts and were gradually increased by steps to 80 volts, in the 4 lower sets, and 70 volts in the 4 higher sets.

The outstanding facts from this series are that a current flow of 0·65 amperes through the filament does not cause an appreciable electronic emission ; the 2·5 milliamperes current indicated is drawn to the plate when 15 volts are impressed thereon, the valve then becomes saturated. Any further increase in plate voltage, whilst setting up an additional strain in the valve, does not increase the electronic flow. When the filament current is increased to 0·70 amperes and the plate voltage is 30, saturation occurs at 9·0 milliamperes, the point of saturation being most marked.

Between a filament current of 0·70 amps. and 0·80 amps. the critical temperature is reached and very marked increases of electronic flow are observed for slight increases of filament temperature. The flow through the valve does not increase materially when currents greater than 0·77 amperes are passed through the filament.

TABLE III.

ELECTRONIC EMISSION WITH GRID DISCONNECTED. CONSTANT FILAMENT VOLTAGE AND VARYING PLATE VOLTAGE.

Voltage of plate.	Amps. thro' Filament.						
	6·5	0·7	0·75	0·8	0·85	0·9	0·95
	Milliampères Current through Valve.						
28	—	6·0	6·0	6·5	6·5	6·5	6·5
30	5·0	6·5	7·0	7·5	7·5	8·0	8·5
35	5·0	8·5	9·0	9·5	9·5	10·0	10·0
40	5·0	9·5	11·0	11·5	12·0	13·5	13·5
45	5·0	10·5	13·5	14·0	14·5	16·0	16·0
50	5·0	11·0	16·0	16·5	17·5	18·5	19·0
55	5·0	11·0	18·5	19·5	20·0	21·0	21·5
60	5·0	11·0	21·0	23·0	23·5	24·0	24·5
65	5·0	11·5	24·0	25·5	26·0	27·5	28·0
70	5·0	11·5	26·0	28·5	30·0	30·5	31·0
75	5·0	11·5	27·0	32·5	33·0	34·0	34·5
80	5·0	11·5	28·0	36·0	37·0	36·0	38·0
85	5·0	11·5	28·5	41·0	42·0	42·0	43·0

The conclusion arrived at is that the operator using these valves should adopt as low a filament current as convenient and a plate voltage just below where saturation occurs. Plate voltage has generally to be obtained at considerable cost, particularly when dry cells are employed.

ELECTRICAL PRECIPITATION.

A final note on the very interesting method of Cottrell for the precipitation of dust, fumes and acids. The most startling application in a commercial way of the Cottrell process was curiously enough in connection with the Cement industry near Los Angeles.

Serious complaints were received from the orange growers respecting the damage that their trees suffered from the fumes and smoke arising from the cement works. As a result of the installation of precipitators, the value of the precipitate as a fertilizer outgrew the value of the cement produced, and the same parties who were the complainants, purchased their bugbear as a fertilizer. Other notable instances of the elimination of a nuisance to the advantage of the eliminator could be cited, particularly in the smelting and refining works; large recoveries of sulphuric acid are made without difficulty and much waste of light metallic dust which had previously gone up the chimney is now saved. The Cottrell process has something akin to the Vacuum valve in its operation, a central element subjected to a high electrical potential is suspended inside a tube through which the gases pass. Usual dimensions for this tube are 4 in. in diameter, and the central member is conveniently a chain. The necessary potential to be impressed on the chain is of the order of 80,000 volts, and as this must be of one sign, negative, one difficulty has been in obtaining this high value.

Attempts have been made to construct a continuous current generator for this purpose, but the difficulties are great. Commercially an alternator is used, run in step with a mechanical interrupter so that half the output is run to earth and the other half is led to the battery of precipitators. When the author was carrying out work on this apparatus there was a limiting speed of gas through the pipes of about 6 ft. a second, beyond which complete precipitation could not be insured. Development is going on all the time, and the author considers that the system has a great future.

There is no doubt that much could be done in England along these lines to eliminate many nuisances now endured.

DISCUSSION.

Dr. J. A. Fleming, D.Sc., F.R.S., said he esteemed it a pleasure to be present at the reading of Capt. Brewer's paper, and to be invited to take part in the discussion. The portion of his paper which interested him most was that in which he deals with the manufacture of the thermionic valve as it was conducted in America during the war in certain places.

Prof. Fleming had gone to the trouble of placing upon the table a number of historic samples showing the manner in which this most remarkable appliance has been developed.

It originated in his study of a certain effect noticed by Edison in the early days of incandescent electric lighting, but of which he (Edison) made no practical application. For some purpose or another, Edison put into the bulb of one of his carbon filament lamps a metal plate carried on a wire sealed through the glass. He noticed that if the filament was rendered incandescent by a direct current of electricity, then a wire outside the bulb connecting the plate and the positive terminal of the filament was traversed by a feeble current of electricity, but if the plate was connected to the negative terminal no current or at most an extremely feeble one flowed through the wire. This became known as the " Edison effect." Edison made no application of it in any way to telegraphy or telephony, and gave no explanation of it, although he put the fact on record in a patent specification.

At that time (1883) Prof. Fleming was the scientific adviser of the Edison Electric Light Co, of London, and shortly afterwards he began to investigate this phenomena by the aid of a number of special lamps, some of which were on the table. He soon found it was due to some material particles given off from the incandescent filament, which carried a charge of negative electricity. He thought then that these carriers were atoms of carbon, and published in 1889, 1890 and 1896 papers read before the Royal Society, the Royal Institution, and the Physical Society giving accounts of his researches on this effect in glow lamps. In 1899 Sir J. J. Thomson showed that these negatively electrified particles emitted from hot carbon in vacuo were not atoms of matter, but something vastly smaller, viz., atoms of negative electricity now called electrons.

But Sir J. J. Thomson also made no application of this discovered fact, although his researches made clear the full meaning of Edison's effect. In 1904 Prof. J. Fleming, with others, was engaged in developing long-distance wireless telegraphy, and the instruments then in use for detecting the feeble oscillations of electricity produced in aerial waves by electric waves were the coherer, invented by Branley and Lodge, and improved by Marconi, and also Marconi's beautiful magnetic detector.

It was, however, desirable to find more sensitive and certain detectors for long-distance work, and in 1904 the speaker discovered that a carbon filament lamp having a metal cylinder surrounding the filament could convert rapid oscillations of electricity or to and fro motions into a current in one direction.

Hence it became possible to rectify electric oscillations, and to make the groups of oscillations audible in a telephone by means of the above-described lamp, which he named an oscillation valve, but is now called a thermionic valve. This instrument was found to be a sensitive, robust and easily used detector of waves in wireless telegraphy.

One of the exhibits was a glass case which contained three carbon filament lamps, in the bulbs of which were sealed respectively a grid or zig-zag of wire, a metal plate, and a plate and cylinder of metal. These bulbs the speaker had had made to his design before 1904, and they were those with which he first rectified high frequency electric currents. An extensive use was made of his two-electrode form or oscillation valve by Marconi's Wireless Telegraph Co. between 1905 and 1909 or so. In 1907 an improvement was effected by Lee de Forest, in the United States, by putting together in one bulb the grid and plate Prof. Fleming had used in separate bulbs, and de Forest thus made a three-electrode thermionic valve. This proved to be a starting point for a new use of the instrument as an amplifier of oscillations. It was then found that a number of such three-electrode valves could be used in series or in cascade immensely to magnify the extremely feeble oscillations produced in wireless serials by the electric waves coming from far-distant stations. Finally, about 1913, it was discovered that the thermionic valve could not only detect electric oscillations but could also generate them.

This had given us a generator of waves for wireless telegraph of enormous utility and one which had completely solved the problem of practical wireless telephony. These discoveries gave us a remarkable illustration of the way in which the most important practical inventions may grow out of abstract scientific researches.

The combination of these two discoveries has given us an enormously sensitive detector of electric waves, and all the wireless wonders that are performed to-day are due to the use of this thermionic valve as a detector and oscillation producer. There was, as can be imagined, room for much detailed invention in converting experimental appliances of scientific investigators into the commercial, compact and reliable instruments needed for use in wireless telegraphy as applied in war and maritime telegraphy. The particular form of valve of which Capt. Brewer had described the manufacture had gradually been called by Naval and Air Force officers during the war the R. Type, or French valve, because the particular form of filament, grid, cylinder, bulb and pins were described in the patent specification of two French engineers, MM. Peri and Biguet, who patented it in France in 1915.

In this form it consists of a straight tungsten filament around which is a helical wire grid, and outside that a cylindrical anode. The bulb is furnished with four pin terminals, which fit into a socket. In this type it has been manufactured literally by millions during the war in England, France and America.

Very large valves, one of which was exhibited, are now used in wireless stations to generate continuous electric waves. These are of the two and three-electrode type. The completed invention of the thermionic valve has solved entirely the problem of radio-telegraphy. The human voice can now be transmitted thousands of miles over land and sea.

Last October a striking experiment was carried out in America in this way. The valve has likewise given us a perfect telephone relay or repeater by means of which we can neutralise the effect of the resistance of the telephone line, and so make an immense economy in copper.

The trans-Continental telephone line in America, New York to San Francisco, would have been impossible of accomplishment without it, but by the use of twelve valve repeater stations it has been found possible to speak over a distance of nearly 4,000 miles.

We can talk now to aeroplanes 200 miles away and miles high in the sky. Submarines can converse with one another under water at great distances, and speech transmission across the Atlantic has been accomplished.

All this is due to this wonderful little glass bulb. Its development has been one of the romances of electrical science, and a striking object lesson in the way in which pure scientific researches of apparently no utility may lead to inventions which revolutionise whole departments of applied science.

Mr. H. J. Deane, M.Inst. C.E., stated that he was extremely interested in the author's description of the electrical apparatus which was dealt with in the paper. The term "Thermionic Valve" until that evening had been a phrase the meaning of which he did not fully appreciate, but the clear description and interesting exhibits, together with the remarks of Prof. J. A. Fleming, D.Sc., F.R.S., had given him a clear understanding of the beauty and delicacy of this piece of apparatus. It appeared to him that the possibilities of the extension of its use were enormous and the field infinite.

To proceed to two matters he was more familiar with, he would like to refer to the use of concrete in the construction of roads in this country. Mr. J. H. Walker, one of the engineers in the employ of the Port of London Authority, had patented a system of reinforcement for concrete roads which was very economical and at the same time simple in application. The agents for this system, the Walker-Weston Co., would, he felt sure, be pleased to furnish full particulars to any of the members who were interested. Great success had attended its use on works of the Port of London Authority, and it had other applications in addition to that for road making.

In regard to the surfaces of concrete roads, he was of opinion that the best results would be obtained by the removal, shortly after the initial set had taken place, of the small particles of cement and sand which were to be found between the coarser aggregate, and if this were done and tar spray applied to the rough surface resulting, and then suitable hogging applied, it would be found that the surface of the road would be less liable to disintegrate than if this precaution were not taken.

On the subject of Electrical Precipitation he was interested to hear that a process had been satisfactorily evolved for the precipitation of dust by electrical means. In handling bulk grain by the pneumatic process there was always a large amount of dust separated from the grain, which had to be returned with the grain for delivery to merchants. In the case of the more usual types of cereals, such as wheat, oats, barley, etc., little difficulty was experienced in collecting this dust by means of the Cyclone Extractor, but in any case there always remained a small quantity of very fine dust which passed through the turbo exhauster or the pump which was not amenable to this treatment.

This more particularly applied to the handling of cotton seed by the pneumatic process. The dust from cotton seed consisted to a large extent of extremely fine cotton wool in such a state of suspension that it was impossible to extract it by means of the Cyclone, and only partially by means of some more recent improvements in the handling of this seed. This cotton dust was injurious not only to the men working the seed, but also to the neighbourhood surrounding the pneumatic apparatus, and he felt sure that if the "Cottrel" process was the success which it appeared to be from the statements in the paper, there was a large field for its application in the handling of such a commodity as cotton seed.

He desired to congratulate the author on the most interesting and valuable paper which had been presented to the Society of Engineers, and to thank the Chairman for the opportunity he had given him for contributing to the discussion.

Mr. M. A. Ockenden said he was not aware that concrete oil storage tanks had been adopted generally, as, during his recent visits to the States, he had not seen such tanks in the oilfields, although he had not been further than the Mid-Continent. Oil companies in other parts of the world were interested in this subject, especially during the war, when steel plates could not be obtained and delivered, excepting at a very high cost, but it was found in most cases that geological conditions would not permit of such structures. He asked the author if these tanks were used exclusively for oil of asphaltic base or had they been used for lighter oils of paraffin base ? Also whether the author had any information regarding ferro-concrete tanks or ordinary concrete tanks of small dimensions which might replace the present steel tanks. The largest diameter steel tanks which were standardised and used on tank farms had a capacity of 55,000 barrels each, and were erected throughout the States.

The author was also asked how evidence was obtainable as to leakage, and whether there was evidence that these large concrete reservoirs were strictly water or oiltight. He could not understand how it would be possible to prove this.

N.B.—Capt. Brewer's reply to the discussion on his paper will appear in a subsequent issue of the Journal.

Delayed Reply by the Author to the Discussion on " Some Modern Engineering Practice in America," published in No. 1 issue of the Journal, 1921.

Capt. R. W. A. Brewer, A.M.I.C.E., in replying to the discussion, said that he was particularly gratified that the meeting was honoured by the presence of Professor Fleming, D.Sc., F.R.S., and by the valuable remarks which he made and the extensive exhibit displayed by him. Professor Fleming's work opened up a new era in wireless telephonic communication, as, by reason of the extreme sensitiveness of the vacuum valve, signals were readable from very weak indications. During the last few years of the war valuable work was carried out in America in tracing spies and other sources of leakages of information in spite of great ingenuity displayed on the part of the enemy to conceal these operations. Vacuum valve detectors approaching an objective from different angles were able to round up many enemies. The meeting will be interested to know that the American seaplane N.C. 4, which crossed the Atlantic, was equipped with valves made in the factory described, and the author showed a valve which he had carried about the world for two years, which operated perfectly on his voyage from America to England. The paper only dealt with the receiving type of valve as these were made at first, afterwards transmitting valves of the same general dimensions were also constructed.

Replying to the remarks of Mr. Ockenden, relative to concrete oil reservoirs, he stated that the work described in the paper was employed to contain California crude oil, he understood, however, that Pennsylvania oil was successfully contained in reservoirs of a somewhat similar though smaller construction, and that satisfactory results were obtained. The elimination of cracks is of paramount importance, but the author was not aware of failures occurring due to hair cracks in the concrete.

Relative to Mr. Deane's remarks on electrical precipitation of dust, the author is fully alive to the possibilities of this method of purifying air, particularly supplies to large public buildings. In fact, when engaged upon this work, he proposed a self-contained unit for the purification of air, as such a system has marked advantages over filtration processes at present adopted.

THE MOTOR CAR PNEUMATIC TYRE.

A Brief Description of its Manufacture, Materials, Types, etc.

By Lieut. J. C. Ferguson, Assoc.S.E. (late Technical Officer Motor and Aero Tyres, R.A.F.).

Materials.

The Materials used in the production of a modern pneumatic tyre are mainly rubber and cotton. In comparison to the price of tyres neither material can be considered costly, and it is solely due to the complex treatment necessary to obtain the desired result that a tyre is expensive.

Rubber.—Rubber—a word adopted because of its long association with the erasure of pencil marks prior to the modern and multitudinous other uses to which it is put—comes to us from the tropical countries, and is the juice of a tree. This juice in its first state presents all the appearance of milk, and is known as *latex* ; it is obtained by cutting or " tapping " the bark of the tree in accordance with certain approved methods, the most common of which is known as " herring-bone."

The latex oozes from the cross incisions into the central (vertical) channel, thence travelling down to the base of the tree. A small vessel to receive the latex is placed at the foot of the channel, and this is emptied into a basin at regular intervals by the native collector. The next step is the coagulation or solidifying of the latex, the methods varying according to the districts in which the trees are situated. The wild Para rubber—still considered the best of all rubbers—from Brazil is treated by coolies in a manner which may be roughly described as follows :—

> One end of a stick or paddle is dipped into the latex, and the latter smoked over a fire until it is more or less dry ; then again dipped and smoked, and so on until the basin of latex has been entirely transferred to the stick and coagulated. The rubber upon being stripped from the paddle is ready for despatch to the tyre factory. With this (wild) class of raw rubber a considerable amount of treatment is required before the process of mixing can be attempted, as the lumps, or " biscuits," often contain small stones, bark cuttings, leaves, etc., and there also is a high percentage of moisture.

Cleaning Plantation Rubber.—In a rubber plantation district a factory for treatment of the latex is usually available. Impurities are removed by passing the latex through a sieve, and coagulation is brought about by chemical treatment. The result effects a considerable saving to the factory, but it is a tribute to the conservatism of the tyre manufacturer that for many years following the introduction of plantation rubber he insisted upon washing and drying the plantation product in exactly the same way as the native wild rubber. Plantation rubber is usually made up in rough sheets known as " crepe."

Mastication.—After washing and drying, the rubber is masticated, that is, it is machine-kneaded into a plastic state, the purpose being to make it readily susceptible to the admixture of sulphur and other ingredients required for vulcanisation.(Fig. 1.) In some tyre factories the masticator (illustrated) is also used for compounding.

Compounding.—The really important work in a tyre factory begins with the mixing of the rubber with sulphur and various minerals selected in accordance with the chemists' experience of what will produce a satisfactory result. The introduction of sulphur is essential to the process of vulcanisation, and it is advantageous to the purchaser of a tyre to know that the process does not end in the tyre factory, but continues throughout the useful life of the tyre, stopping only when the rubber has completely rid itself of its complement of sulphur. We may look upon raw rubber and sulphur as we do upon two persons between whom no love is lost, but who temporarily combine forces for some highly commendable purpose. Litharge is employed to toughen the rubber and to assist vulcanisation, a remark also applying to carbonate of magnesia and zinc oxide. Many tyre manufacturers use two, three and some times four different mixings of rubber with which to build up their tyres, the intention being to obtain a tough tread, a highly elastic tread base or cushion, and resilient though reasonably strong walls. A special hard mixing is necessary for the beadings. The ingredients used in the manufacture of inner tubes are, of course, very different from those employed in the outer cover, the essential point in the former being a high degree of elasticity. Crimson antimony is employed to colour the popular red tube, and though it is maintained in some quarters that the latter presents no superiority over the grey tube, the author's experience inclines him to think that it has.

The rubber, sulphur and other ingredients are mixed in a mill not in appearance unlike the ordinary household laundry mangle, but with hollow metal rolls, steam-heated or water-cooled at will in accordance with requirements (Fig. 2). The temperature maintained affects the consistency of the compound, and hence

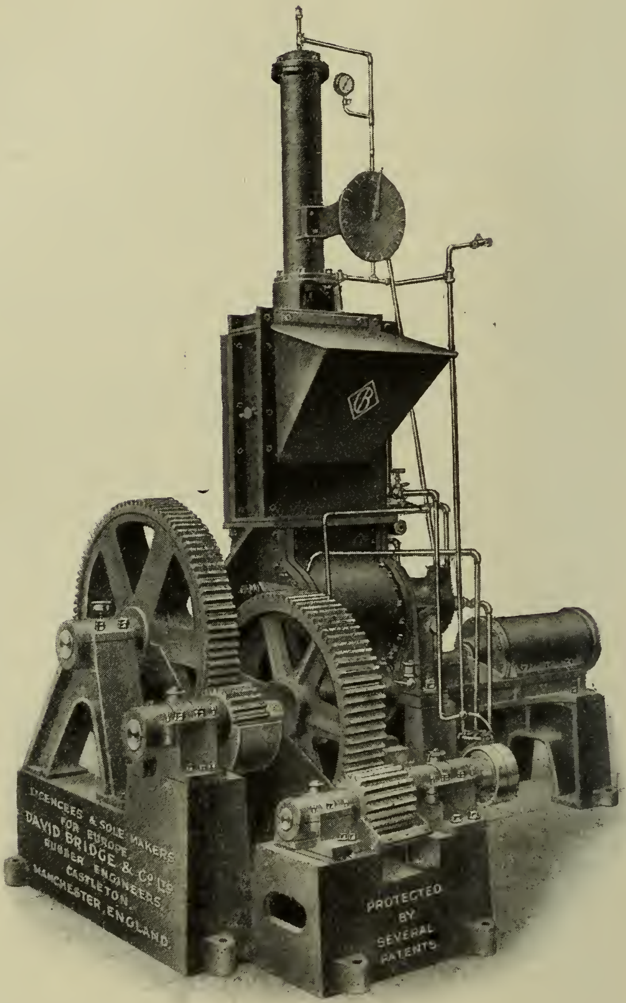


Fig. 1.—RUBBER MASTICATOR

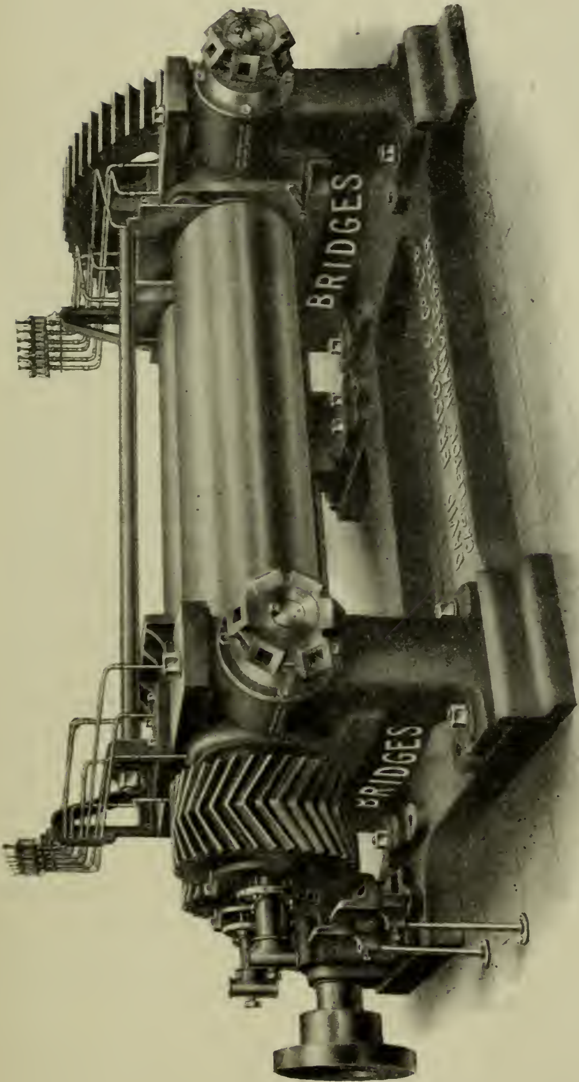


Fig. 2.—Compounding Machine.

varied mixings necessitate different treatment. The rubber first and later the minerals are fed on to the revolving rolls, the entire mass being occasionally passed through to permit its reintroduction in bulk with consequent improved blending of the materials. The final result is a smooth sheet of plastic rubber or compound, which is rolled or calendered on to a wrapping cloth to prevent the adhesion which otherwise would occur.

Cotton.—The cotton used in a pneumatic tyre is described by the spinner as tyre canvas duck. The best quality is known as long staple, the two finest varieties of this being Egyptian and Sea Island (U.S.A.). The length of the staple is an important point, and for tyre purposes the highest grade of long staple cotton should always be and generally is used. That there are many cheap grades of cotton is one reason why some tyres break up soon after use on the road. Most manufacturers, however, have recognised that to stint the tyre of really good quality fabric leads to trouble. The canvas duck is made up in the spinning mills in wide sheets, and forwarded to the tyre factory. It is there tested for strength of warp and weft, and, should the slightest sign of moisture betray itself, is thoroughly dried. The presence of grease or foreign matter being inimical to vulcanisation calls for rigid inspection. Here it is to be noted that even in the best regulated factories an occasional fault escapes detection, and may, notwithstanding the perfect execution of all successive operations, ultimately cause the collapse of the tyre in service.

Proofing the Canvas Duck.—The work of impregnating and spreading the canvas with rubber is performed either in the tyre factory or by firms who specialise in proofing. The words "impregnating" and "spreading" are here used with the intention of conveying two important conditions to be attained before the fabric can be considered to fulfil satisfactorily the requirements of a pneumatic tyre. Impregnation and spreading are, it is true, carried out in the same operation, but to a certain extent are distinct in the parts they play when the tyre is in use. The saturation of the fabric with the purest grade of rubber solution ensures protection to the strands of the material which would otherwise chafe and quickly break up.

Spreading, on the other hand, is the *coating* of the fabric with the same quality of rubber solution used in impregnation. The thin layer of rubber separating each ply of canvas of the tyre casing (or carcase, as it sometimes is called), constitutes one of the vital parts of the pneumatic tyre, and its chief function may be described as follows :—

> A tyre in movement is subjected to an extraordinarily severe stress at that portion abutting the ground, whereas the upper portion is free from stress except that due to the air pressure from within. The revolution of the wheel,

therefore, means that each portion of the tyre has moments of freedom and of stress, and that there is no constant stress on the complete tyre. This jerking on and off of the stress is resisted only by the elasticity of the rubber, and not merely the rubber forming the tread of the tyre, but that lying between the plies of canvas. The casing thus adapts itself to the stress and resulting strain—it, in fact, bends and stretches but does not break. Take away the layers of rubber and the casing will succumb in an expensively short time.

The proofing of the canvas also enables the formation of the several plies into a single flexible unit, *i.e.*, the casing, but the author wishes to emphasise particularly the relation of the rubber layers to road stresses, inasmuch as the point is not generally understood or appreciated outside the tyre factory.* Faulty proofing of the canvas is, fortunately, not so common a defect as it was ten years ago. Nevertheless, as it is one that usually affects a large number of tyres, if any at all, systematic and careful inspection of the finished article is adopted in the factory prior to the building of the casing.

Building the Casing.—The operation of building the casing involves the use of a core which in appearance resembles a spoke wheel, but has a rim of the shape and inside dimensions of the size of tyre required. The canvas is cut in strips to the required length and breadth. As a rule the casing consists of several strips of canvas spliced together, but the adoption of a single continuous strip has been considered, and offers many attractions. The more splices in a casing the greater the risk of rupture when the tyre is put into service, and it is to be hoped that the single strip will become a recognised feature of tyre building. When several strips are employed, the operator is compelled to use the utmost care to see that the splices are not concentrated at one point of the casing, as this would mean a serious defect in the finished tyre.

An important point is the cutting of the canvas on the bias, or at an angle of 45 degrees to the warp (lengthwise strands) of the material (Fig. 3). The reason of this is that the strip cut on the bias conforms readily to the shape of the tyre, whereas the reverse effect would be obtained by straight cutting, *i.e.*, a mass of wrinkles would gather at each side of the strip, rendering further progress impossible. Another advantage gained by cutting on the bias is that the road shocks sustained by the tyre are not taken at right angles—broadside on as it were—to the strands of fabric, but obliquely, and consequently with less likelihood of fracture of the casing.

---

* If the tyre be soft (due to under-inflation or deflation), the stress caused by road usage is enormously accentuated, and disintegration of the casing follows.

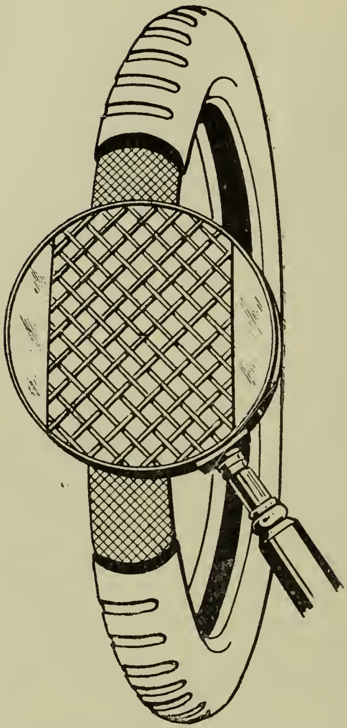


Fig. 3.—Section of Tyre showing how Fabric is cut on the Bias.

The canvas having been cut on the bias, it is mounted on the core. Until comparatively recent years tyres were built by hand, and it was at one time thought that the human element was an essential to success. That contention, however, has been completely disproved, and modern machinery—under supervision, of course—makes the best pneumatic tyres. The great weakness of tyre construction by hand, curiously enough, is the human element held in such veneration in days gone by. The operator's attention to his work becomes distracted, or towards the end of the day he tires of what undoubtedly is an arduous task ; however it be, the canvas demands an even tension from the first ply to the last, and any looseness, or, on the other hand, tightness, means the ruination of the tyre. The French Mathern machine, made in Zurich, and used in many tyre factories, replaces the functions of the core and the duties of the operator (Fig. 4). The fabric is mounted on the core by the building machine, and is neatly rolled into the shape of the tyre. The operator regulates the speed of the core, and the supply of canvas,

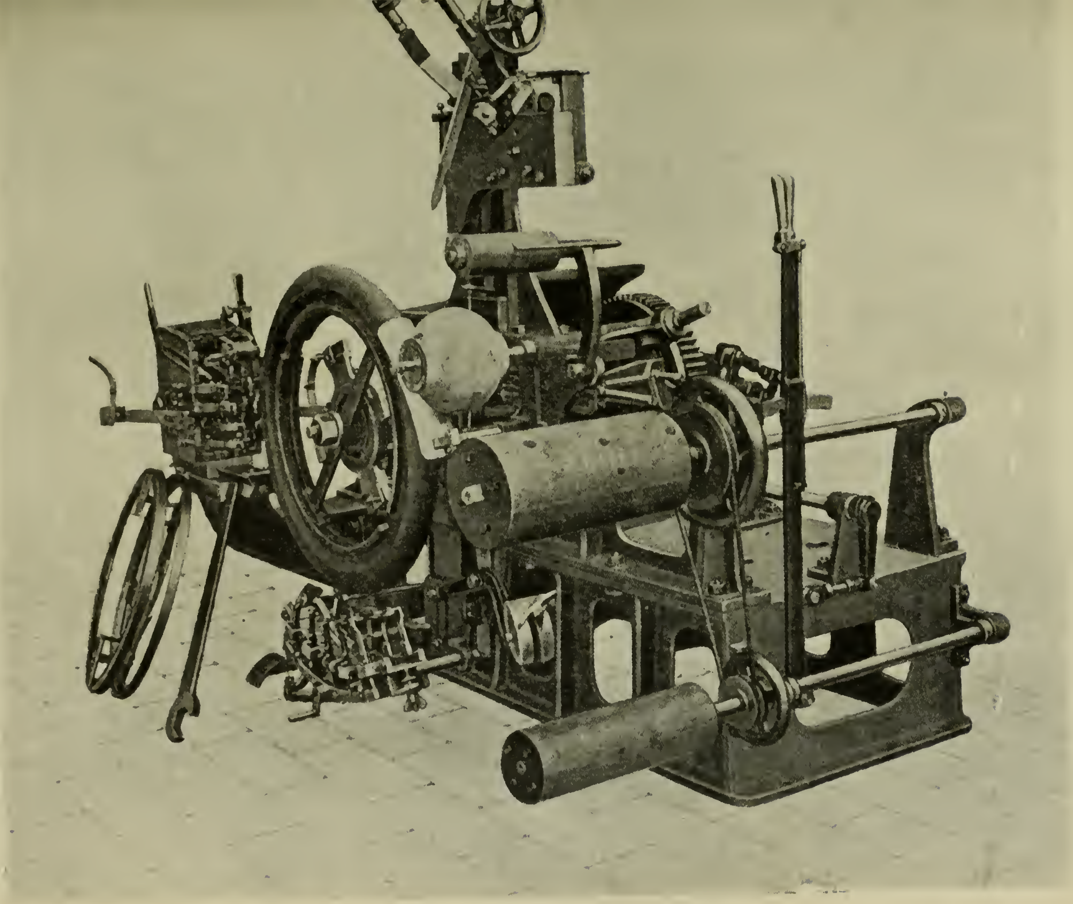


Fig. 4.—Tyre-building Machine.

and in general sees that all goes well. A not unimportant advantage is that almost all handling of the fabric is dispensed with, perfect cleanliness being essential to successful tyre building. When a few plies of canvas, the number depending upon the size of the tyre under construction, have been laid on the core, one upon another, the work of building the casing is temporarily stopped, and the bead cores of hardened rubber covered with fabric are fitted into position. Bead cores are produced by a forcing machine in long strips of plastic compound of the required design. The tyre-building machine thenceforward and until the casing is finally completed rolls the remaining plies around the beads coincidentally with the main body of the casing. For additional strength at a vulnerable point one or two narrow strips are sunk into the beads, brought around to, and about an inch up the side of the casing, and are there enclosed within the layers of rubber constituting the walls of the tyre.

The Cushion.—Inspection of the cross section of a good class pneumatic tyre reveals the presence of a distinct and highly resilient rubber laid between the casing and the tread. This cushion serves several different purposes. Firstly, it is the binder of the tread and the casing, and exemplifies the extraordinary tenacity of rubber in performing this function. Separation of the tread from the casing was at one time the skeleton in the cupboards of all tyre factories, but the adoption of the cushion base has largely overcome trouble of this description, always providing that the tyres are properly inflated. Secondly, the cushion lends valuable assistance toward conformation of the tyre to road stresses ; and, thirdly, it shields the comparatively brittle casing from the many severe shocks sustained during the useful life of the tyre.

The fitment of the cushion base completes the building of the casing.

Preparation of the Tread.—The tread is constructed by hand of strips of the plastic rubber or compound described earlier in this Paper. The strips may be $\frac{1}{8}$ in., $\frac{1}{16}$ in., or $\frac{1}{32}$ in. thick, and are cut in varying widths, the object being to obtain a substantial centre with tapered edges. In some factories the tread is "spewed," or forced through a machine in one complete piece of the required shape and dimensions, the process much resembling that employed in the manufacture of solid tyres. A singly ply of coarse fabric, known as the breaker strip, is inserted as a foundation for the tread, its purpose being the protection of the casing and also the strengthening of the tread.

Application of the Tread to the Casing.—The tread may be built upon the casing, as already described, or separately, the method adopted being dependent upon the vulcanising process subsequently to be employed.

VULCANISATION: SINGLE *versus* DOUBLE CURE.

Methods vary in the curing or vulcanisation of pneumatic tyres.

Single Cure.—The single cure means that the tread in its plastic state, having been fitted on the casing, the *complete unit* is vulcanised in one operation. The advantages of this method are that the soft rubber in all parts of the tyre is transformed into its tough vulcanised state at one time, the result being a general and compact amalgamation of the materials. An economy in production also is effected. The disadvantages are that if any mistake has been made in the quantity of materials used the tyre may be a failure, and cannot conscientiously be issued for sale. One such defect is that known as " pinched fabric " (a crease caused by the mould), of which, unfortunately, examples are still not uncommon, and considerably reduce the wearing value of the tyre. The manufacturer often is quite unaware of the defect until the tyres come back to him from his customers—unaccompanied by the usual mileage testimonial.

Double Cure.—By the double cure the casing and the tread are *separately* half-cured, after which they are inspected, and, all being well, united and the cure completed. With this process the tread may either be press moulded or built up on a core, and when semi-cured, wrapped on the casing and fully vulcanised. It is a common mistake amongst motorists to imagine that a tyre bearing the mark of cloth wrapping is a retreaded tyre. The latter description always implies a secondhand casing, and there is a wide difference between a new casing and one that has seen long service on the road.

VULCANISING PLANT.

The moulds (Fig. 5) used in tyre factories form an exceedingly heavy item of expenditure, and as many sizes are essential to the conditions of the trade it is not surprising to learn that manufacturers have recently been putting their heads together with a view to reduce the number, standardise such as are really necessary, and to discard the others. The mould consists of a metal core and two shells, the former, as the word implies, fitting inside the tyre, which is enclosed by the shells. The Autoclave combined vulcaniser and hydraulic press (Fig. 6), being essential to both the single and double cure processes, is in popular use in all modern tyre factories. From ten to fourteen filled moulds form a batch for treatment at one and the same time. In the double cure process the Autoclave is employed for the curing and pressing of the casing in a special mould, the subsequent vulcanisation of the complete tyre being effected in a large horizontal pan. With the single cure process the horizontal pan is not required, the

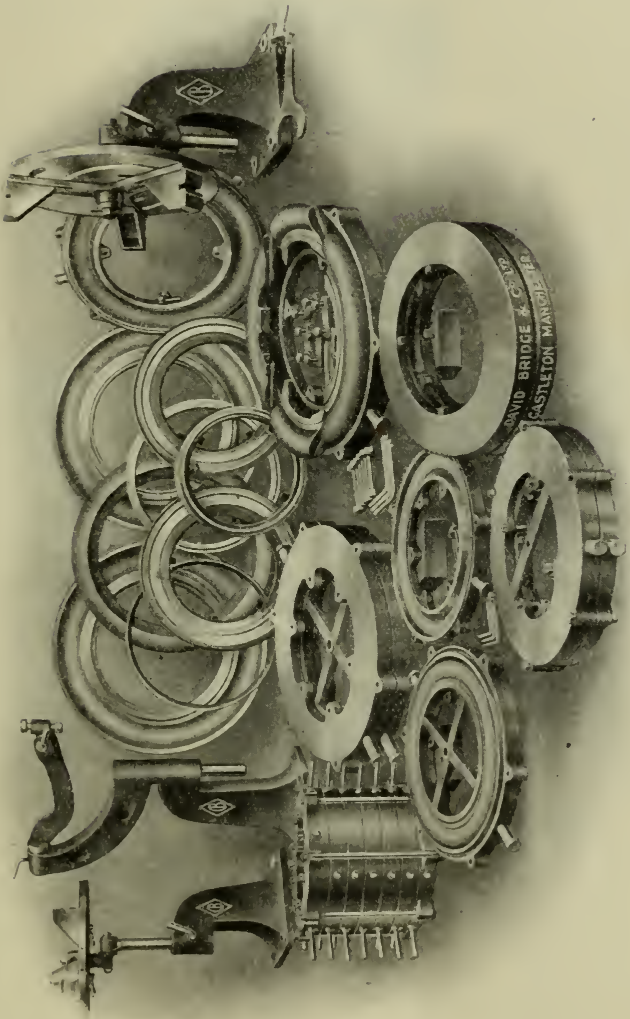


Fig. 5.—Tyre Moulds.

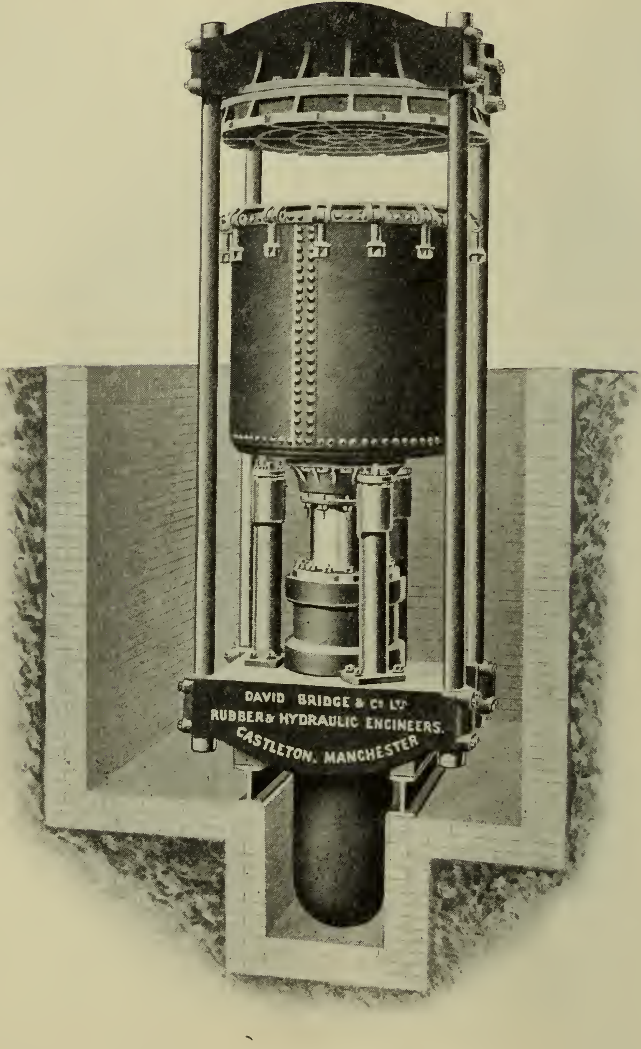


Fig. 6.—Autoclave Combined Vulcaniser and Hydraulic Press.

tyre being vulcanised by one cure in the Autoclave. The mould in this instance is of the dimensions and design of the complete tyre. The heat is that of steam at about 40 lbs. per sq. in., and hydraulic pressure 2,000 lb. per sq. in. A tyre is vulcanised by the single cure process in about 90 minutes.

INNER TUBES.

The plastic rubber compound, cut in suitable strips, is applied to the circumference of a long metal pole. The edges of the material are neatly joined and rolled by hand, and the whole firmly bound round with strips of cloth. Vulcanisation follows, and the tube is blown off the pole by compressed air The ends are bevelled, and then joined by the cold cure (chemical) process of vulcanisation. The insertion of the valve completes the operation, and the tube is ready for use on the road.

TYPES OF PNEUMATIC TYRES.

The Cord Tyre.—The casing of a cord tyre is totally distinct in type from that of a fabric tyre, and is a much more scientific achievement of tyre construction. The casing is built in the tyre factory by a special machine, the cords being diagonally laid from bead to bead, the layers thus formed alternating in direction *i.e.*, the top layer cords *crossing* those of the lower layer.

The great point of this system is, however, the impregnation of each single cord with rubber, the result being a flexible casing far less likely to chafe and break up under the stress of the road than the fabric tyre. The principal objection to the cord tyre is its high cost ; great difficulty, too, is experienced in repairs, which can only be carried out properly in a factory. No higher tribute can be paid to the cord casing than that of the war. The lives of our flying men often depended upon the tyres used on the aeroplanes, and these were all of the cord type, the strength of the casing being relied upon to make good the absence of a heavy tread.

The Straight Side Tyre.—In foregoing pages of this paper the tyre described has been the regular clincher beaded type, popularly used throughout this country and on the Continent. The principle, so far as attachment to the rim is concerned, is that curved or clincher *extensible* beads on the tyre coincide with curved or clincher lips on the metal rim, and that the latter retains the tyre in position on the wheel. The rubber core in the beads, though hard, is flexible, and the tyre therefore can be levered over the lips of the rim.

With the straight-side tyre, which, by the way, is the most favoured type in America, the beads are made *inextensible* by the insertion of wires or by other means, and the tyre holds itself on the rim. The raised sides or flanges of the rim form "embankments," which prevent the tyre slipping off; one of these flanges is detachable, and permits the removal of the tyre at will.

As an engineering job, the straight-side tyre must appeal to most people as the better of the two types. As will be seen by inspection of the cross sections shown in Figs. 7 and 8, it has a larger air capacity, meaning improved cushioning effect with increased mileage. The straight edges or beads are simple and effective, and do not call for the aid of security bolts to keep the tyre on the rim. The tyre never suffers from rim-cutting unless run upon in totally deflated condition. The flat beads are less likely to pinch the inner tube than the clincher beads with their pointed "toes."

Comparison of the two types of tyres cannot, however, fairly be made without bringing the question of rims under review, and here the clincher rim makes good for the faults of the clincher bead tyre. If not absolutely satisfying to the eye of the engineer, it at least is solid and substantial, which the straight-side rim is not. The detachable flange on the American rim is a source of great trouble to the motorist, and forms the weak link in what otherwise would be a strong case for the straight-side tyre. The author's opinion is that the future will see the production of an improved detachable rim, and that the straight-side tyre will then be universally adopted.

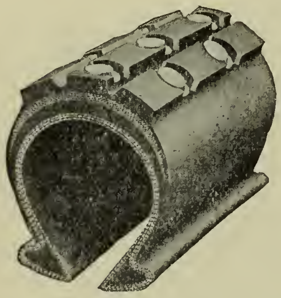


Fig. 7.—Cross-section View of a clincher beaded tyre.

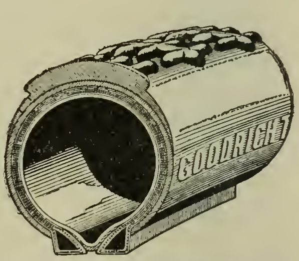


Fig. 8.—Cross-section View of a Straight-side Tyre.

Tread Designs of Pneumatic Tyres.

Tread designs may be divided into three categories, viz., steel-studded, rubber anti-skid, and plain.

Steel-studded.—This is the most expensive type of tyre from the point of view of both initial cost and cost per mile. Its value is in its anti-skid and anti-side slip properties, and on this point it should be mentioned that the Competent Authority on the London traffic regulations decrees that every taxicab in the Metropolis must be fitted with two steel-studded tyres.*

The motorist in buying a steel-studded tyre is buying safety, and is to be strongly upheld in sacrificing economy to so good a cause. One steel-studded tyre, is, however, quite sufficient for cars used over macadamised roads only, the real danger of side-slip existing on paved and asphalted streets covered with greasy slime.

Plain.—The features of this type are in direct opposition to those of the steel-studded pattern. The plain is the cheapest of all types of tyres, both in purchase price and in cost per mile. Were economy the sole consideration, all four wheels should be fitted with plain tyres, not alone because they last longer than either steel-studded or rubber anti-skid tyres, but because they are less liable to pick up the nails, flints, etc., that litter our streets. Furthermore, the plain tyre requires fewer repairs and gives less trouble on the road than other types—valuable features in themselves. Unfortunately, however, for the economist, plain tyres both skid and side slip dangerously on greasy streets, sand drifts, or other unstable surfaces, and their adoption as an all-round equipment of the car would be nothing short of folly. The plain tyre can only safely be used in conjunction with the steel-studded tyre.

Rubber Anti-skid.—This type includes all rubber tread covers containing grooves, ribs, corrugations, and the like. In price it usually comes about midway between the expensive steel-studded cover and the cheap plain. In mileage it produces better results than steel-studded covers and inferior results to plain covers. In anti-skid properties on greasy surfaces it bears poor comparison with steel-studded covers, but is less dangerous than plain. It is more costly in repairs than plain, but cheaper than steel-studded.

Taking all three types and awarding two points each for (1) safety, (2) mileage, (3) cost, we obtain the following results :—

	Safety.	*Mileage.*	*Cost.*	*Total.*
Plain	—	2	2	4
Rubber Anti-Skid	1	1	1	3
Steel-studded	2	—	—	2

The essential feature is safety, and steel-studded covers, however lacking in other good points, must therefore be used. On paved or asphalted streets the equipment should be two steel-studded covers, one on the near rear wheel and the other on the off front wheel. This arrangement ensures all reasonable safety, and only an excessive speed can cause danger. If the motorist is prepared to content himself with ordinary speeds on greasy surfaces he is safe in using two plain covers on the off rear and near front wheels, and by doing so is combining economy with safety. If he possesses rather more worldly riches than the ordinary man in the car he may further ensure safety from accident by fitting a rubber anti-skid tyre on the off rear wheel instead of a plain tyre. It becomes extravagant if two rubber anti-skid tyres are fitted instead of two plain. It should be remembered that the plain and rubber anti-skid types are the best non-slipping tyres on dry streets and steel-studded tyres the worst. So that from every point of view it is a great mistake to fit more than two steel-studded covers on any car ; the day may be rainy or fine, and a steel-studded cover is almost as dangerous a tyre on a dry surface as a plain tyre is when the road is wet.

---

* This decree was temporarily amended to one steel-studded and one rubber anti-skid cover owing to the shortage, occasioned by the war, of the former type of tyre.

For a car, the operations of which are practically confined to country macadamised roads, the above arrangement may, without risk, be modified in favour of economy by fitting one steel-studded cover on the near rear wheel with a rubber anti-skid tyre on the off front wheel and two plain covers on the remaining wheels. It is hardly necessary to say that the likelihood of skidding and side slip is much reduced on macadamised roads, and that the greatest need for caution in driving occurs on the paved or asphalted street.

Combination Steel-studded and Rubber Anti-skid Tyre.—Several manufacturers produce this type of tyre, but as the designs differ in almost every instance it is impossible to here enter into details. The principle is, however, that by riveting steel studs within suction cups or grooves on the tread the tyre resists skidding and side slip on dry *and* wet surfaces alike. To obtain this result the combination tyre should be used on both rear wheels instead of being diagonally placed as in the case of the ordinary steel-studded cover.

CROSS SECTION SIZE OF TYRES.

In considering the choice of tyres there remains the question of size of section. This depends, or rather ought to depend, upon the weight of the car when fully loaded.

A car is under-tyred when the tyres are of too small a section to stand up to their manufactured shape under the weight of the car with passengers and luggage all on. The conditions, indeed, correspond with those of a tyre of large section insufficiently inflated. There is the same flattening-out effect, the same poor mileage result, the same constant trouble with bursts and punctures on the road.

Not every car sold is properly tyred, and one of the first steps the purchaser should take is to discover what changes, if any, are necessary for the economising of his future tyre expenditure. Simply to follow on with supplies of tyres of the same size as originally fitted may prove a very costly mistake. The procedure should be to note both the size of the tyres and of the rims; to weigh the car fully loaded, and then to ascertain by reference to the tyre manufacturer's weight tables if the tyres are of the correct cross section size or too small. In the latter event a larger size suitable for the same rim should be fitted to the rear wheels, the original tyres being all gradually used up on the front wheels, and finally replaced by the large size.

Cases in which the largest possible tyre capable of being fitted on the rim has still been too small for the weight carried have been known; the only remedy in such instances is to change the rims, and, if need be, the wheels.

Tyre Repairs.

In the repair of a pneumatic tyre the methods used are similar to those of manufacture. Fractures are remedied by cutting away the damaged portion of the tread and casing, the plies of canvas being stepped out and replaced by new strips. As in manufacture, naphtha is the rubber solvent employed in repair work. New plastic compound replaces the old, and the section thus fitted is vulcanised in a cavity mould. Retreaded tyres are vulcanised in a pan similar in design to those used in manufacture but of smaller size.

The Puncture-proof Tyre.

An extraordinary number of attempts have been made to produce a puncture-proof tyre, but so far without any real success. There are to-day, unfortunately, no signs or symptoms that would encourage us to hope for better things in the near future. Metal cannot be made to combine satisfactorily with rubber, nor can any filler compete with air pressure in suitability for pneumatic tyre purposes. But we must remember that just as Goodyear and Hancock astonished the world eighty years ago by the great discovery of vulcanisation—the conversion of a soft, sticky and almost useless substance into a tough, serviceable product—so may we yet see an elastic substance capable of withstanding abrasion. Vulcanised rubber takes us a long way, but, alas, fails to attain completely the ideal of which manufacturers and motorists alike dream.

DISCUSSION.

Mr. Oswald M. Shepherd asked whether the author was of opinion that punctures were a real trouble to-day? The speaker's experience with pneumatice tyres commenced in the days of the red flag man in front at 4 m.p.h. With single tube tyres in those days punctures certainly were troublesome; other troubles were also numerous—with tyres taped on the rim and others cemented with "sticky tac," it was no small job to remove those old tyres from their rims when occasion arose.

With the modern tyre, in Mr. Shepherd's opinion, the external punctures were few until the tyres became nearly ready for the "rag-man." Did the author not think that we had more trouble from improper tyre fitting, damaged rims, rusty and sometimes faulty, leaky valves, which, up to now, have not been made to a standard with interchangeable parts?

Most of the speaker's tyre troubles had been caused by valves. A number of people were not careful to insure that in fitting a tyre it was perfectly clean inside, and that the tube was clean outside, for small sharp grit could, in time, work into the tube. This trouble was often put down to be a puncture through the cover. Nipping the tube, and damage to it with levers by careless fitting, was also accountable for many failures.

Mr. G. A. Parsons said Mr. Ferguson had referred to the straight sided tyre as being in America the most favoured type. It may interest the meeting to know some of the reasons which were believed to have led to the general adoption of the straight sided type by American tyre makers. It was generally recognised that for various reasons, some connected with the tyre and other with the rim, the American Clincher, or, as we should term it in this country, beaded edge tyre, had never been so successful as the beaded edge tyre made by European tyre makers. Eight or ten years ago the American Clincher tyre was undoubtedly decidedly inferior to its European counterpart. This shortcoming was recognised by American tyre makers, who had, in a tentative manner, experimented with tyres of the straight sided type, which were originally used on a modification of the Q.D. or quick detachable rim, certain types of which were supplied with reversible rings enabling the user to employ either clincher or straight sided tyres. Like most devices intended to fulfil two functions, this dual purpose rim was not altogether satisfactory, but the experience gained of the straight sided tyre in this way seemed to decide the American tyre makers to pursue the matter further, with the result that during the earlier part of the recent war American tyre makers induced the automobile manufacturers of that country to adopt the straight sided tyre as the standard equipment.

There appeared to have been in America a much closer co-operation between tyre maker and car maker than could have been looked for either in this country or in France. When a tyre with a somewhat similar type of attachment was introduced into this country some seventeen or eighteen years ago, it met with little commercial success, because car makers were disinclined to supply the special wheel the tyre called for, and users generally were unwilling to go to the expense of converting wheels, with the result that this most promising tyre was eventually withdrawn from the market.

In the speaker's opinion it had yet to be demonstrated that the straight sided tyre was superior to a well made beaded edge tyre, but he recognised that the risk of injury to the tube, when the tyre was deflated was probably less with the straight sided than with the beaded edge.

Whatever the opinions of European tyre makers may be as to the relative merits of the two forms of attachment, they were now committed to the manufacture of the straight sided tyre, unless they were prepared to see the greater part of their business with India, South Africa, Australia and other export markets, pass entirely to the Americans. So many American cars fitted with straight sided tyres were shipped to these markets by the Americans during the war and subsequently, that at the present time the replacement business of these markets calls for 60 per cent. of straight sided equipment, and this demand might be expected to increase at the rate of about 10 per cent. per annum.

There was no reason to believe that English tyre makers would not eventually produce a straight sided tyre equal and probably superior to any of the American tyres, and, as Mr. Ferguson had mentioned, there was great scope for an improvement in the rim for use with this tyre.

He was disappointed that Mr. Ferguson, with his experience in the Royal Air Force, had not referred to the use of twin pneumatic tyres on the rear wheels of the Crossley tenders. It would have been interesting to know what advantage, if any, these were considered or proved to have over single tyres of larger section.

Mr. J. A. Taylor (Birmingham), complimented Mr. Ferguson on the very lucid way in which he had dealt with the subject, and thought that the illustrations given had made the lecture interesting and instructive.

He was rather surprised that the lecturer should have given his benediction to plain and steel studded covers. Most people associated with the motor trade had agreed that the period of usefulness of the plain cover and the steel studded cover had passed, and that the day of the rubber studded cover had arrived.

Mr. Ferguson agreed that for the ordinary macadam roads the ordinary rubber cover was all that was necessary, but claimed that the conditions in London demanded steel studded covers, and that the taxicab authorities insisted on these being fitted to cabs in London. Mr. Taylor said that he was certain that as soon as the authorities had had time to make complete tests of the rubber studded cover, that they would be convinced that the necessity for a steel stud to be fitted to taxicabs had passed, and that the rubber studded would be quite as effective under the conditions existing in London.

In regard to the straight sided tyre, he was of the opinion that these had a future, but he doubted all the virtues that had been claimed for them.

It appeared to him that the Americans, who never had invented anything in connection with the pneumatic tyre, when we were busy at the war, thought it was their duty to invent something, and they struck on this wired on attachment. There was nothing particularly new in regard to it, as it had been in use in cycle tyres and motor cycle tyres for many years, and its general adoption in America by manufacturers did not mean so much as appeared on the surface, as their close financial arrangements existing between the tyre companies and the car manufacturers might reasonably account for its hurried adoption.

It appeared to him that it would have been more satisfactory if the ingenuity of the American inventor had been applied to devising some proper rim and flange for this tyre before putting it on the market, as it was notorious that, at present, this was causing considerable trouble in this country, and if the straight side cover was to be adopted generally in this country, he felt sure that the English wheel engineers would design some reasonably good mode of attachment, and would not depend on the crude specimens that we have received from the other side.

He agreed with the lecturer that the future of the cord tyre as manufactured to-day was likely to be a bright one, and that it was possible it would, in time, for most of the sizes, oust the canvas casing.

Mr. A. E. Parnacott, M.I.A.E., said that when one considered the way in which a tyre was depressed on contact with the road, and the number of layers of canvas, one could not help being impressed by the necessity of these walls being as thin as was consistent with strength.

The speaker thought it could not be structurally sound to build up a cover with layers of canvas, being of the opinion that the cover must be built up as the Palmer cord, or else of fabric woven, not as a flat material, but woven into the shape of the cover. One could not be other than surprised at the length of the life of the ordinary canvas type. He, however, from experience from the beginning of tyres, preferred to use Palmer Cords.

The author mentioned the layer of resilient rubber between the tread proper and the canvas. He asked the author if this resisted the tendency of the tread to creep by yielding and recovering from shear stress.

The speaker had been to much trouble to investigate the causes of tyre tread wear, and *à propos* of that, he had noticed that with tyres having transverse grooves—a common example of which was the Dunlop Grooved Tread—the portion of the tread adjacent to the groove, and which first made contact with the road surface, did not wear so rapidly as that adjacent to the groove following in contacting with the ground. In fact, to use an engineering term, the tread wore as if it were backed off or relieved as was a milling cutter, only to a lesser degree. It appeared that this creeping was due to the rubber being compressed when it must spue out both at the sides and in front, and the bulge in front rubs the ground. He was of the opinion that the extraordinarily long life he had found with the Avon Cross Grooved Tread was due to an absence of the bulge surface rubbing the ground. He thought such a tread on the Palmer Cord Tyre would be very hard to beat.

There was one little known or suspected cause of tyre tread wear. It was that due to the lateral movement of the tyre tread on the road consequent on the wheels being carried on a rigid axle. Some seeming inconsistencies in the wear of large wheeled and small wheeled vehicles led him to conclude—which conclusion was later confirmed by both the scalloplike tyre tracks in the dust, and the polished surfaces of the L.C.C. tramway central slot rail—that to mount wheels on rigid axles was a mistake if the maximum tyre economy were sought. It was difficult to explain, but if we pictured an end view of the back axle travelling on the road surface, and noticed one wheel drop into a depression, or mount one of the all too commonly projecting gratings, it would be found that the lateral movement was something like one inch, when the fall of the wheels was two inches into a pot hole or two inches rise over a grating. This lateral movement must mean that the tread was actually rubbing the road surface, and accounts for the greater mileage economy of the larger sectioned tyres. This lateral movement accounted for the greater tendency to sideslip for a given surface, when that surface was uneven. It also accounted for the much shorter life of tyres under cars with a high centre of gravity, such as limousines. Such was not the case with the Ford, or similarly sprung vehicles, where the springs were tranverse and the shackle allowed of this unsuspected wheel and axle movement without imparting so much lateral movement to the body above the springs.

Mr. L. T. Godfrey-Evans (Member) said that from the remarks of the previous speakers it was evident that opinions widely vary as to the vulnerability of tyres to puncture from nails lying on the track of the roads and that it made no difference whether the tyres were new or old. One speaker, however, inferred that new tyres were more immune from such accidents, and that when such did occur, it indicated that the tyre's term of usefulness was drawing to an end. Tyres were too expensive to be discarded for punctures only, and, when punctured, the sooner repaired the better for the tyre. The time lost, however, was not in executing the repair, but in the taking off and replacing the tyre on the rim. One speaker mentioned three hours as the possible time. Under fairly reasonable conditions a burst tyre should be repaired and the car ready to proceed on its journey in less than forty minutes from start to finish. Occasionally such accidents happen when a delay was a serious matter, and in such cases a detachable wheel rim becomes a *sine qua non*, and, as there were several on the market with varying qualifications, the time should soon come when a car would be considered incomplete without having such an equipment.

In the case of the "Instant Detachable Wheel Rim," with which the speaker was conversant, and which was manufactured by the Company at 6A, Tudor Street, Blackfriars, E.C., the damaged inner pneumatic tube could be replaced by a "spare tube" without even taking off the tyre; within from two to three minutes, and the car was then ready to proceed on its journey, thus saving time and labour.

Whatever the present form of complete wheel rims, the rubber was apt to stick, due to the formation of rust in the jointing, where the jointing was more or less incomplete, which, in the case of detachable rims, hardly applied. In connection with the present form of rim, the speaker would like to know the author's experience in the use of graphite as a remedy for the prevention of rubber sticking to the metal and to facilitate the subsequent easy detachment of the tyre from the rim. With detachable rims the "spare wheels" were not required.

The author replied that graphite, as stated by Mr. Godfrey-Evans, was the article he used for making a sound joint, and for the prevention of rust, which was due to water lodging in exposed joints during wet weather on the roads, or in the operation of washing the car. The author suggested that wheel rims should be made of rustless steel as a remedy against possible rust.

Mr. William M. Beckett, M.B.E., Assoc.M.Inst.C.E., gave some particulars of the construction of the "Hawksley Pneumatic Wheel." This wheel consists of a steel plate stamping, fitted with solid rubber tyres, and provided with three or four air cushions. Each cushion consists of an inner tube and two outer discs or covers surrounding and supporting a central pin, each end of which is attached to a radial arm fixed on the main axle, one arm on each side of the wheel. The axle passes through a circular hole in the wheel allowing ample clearance. The effect of this arrangement is that the whole weight of the car rests on the air cushions. The outer discs of the cushion are made by wrapping cord round two steel rings, the outer one 9 in. diam., and the inner one about 1½ in. diam. The corded rings are placed in a suitable mould and impregnated and covered with rubber under pressure. The moulded discs are saucer-shaped having a semi-circular section.

This wheel was patented over ten years ago, but, unfortunetely, has not yet been put on the market owing largely to insufficient capital.

Among the advantages claimed are :—

Punctures impossible ;
No spare wheel required ;
Flexible drive ;
Side slip much reduced owing to the side play in the cushions.

Having driven several hundred miles in a car fitted with these wheels, the speaker agreed with the claim made that they are quite as resilient and comfortable as the best pneumatic tyres.

Mr. Laird Nuttall asked the author whether he agreed that the secret underlying the success of pneumatic tyres depends largely on the air volume contained in the tyre. This, he thought, was now generally accepted—not by any theoretical reasoning, but by rule of thumb and practical experience.

Indeed, the speaker was of opinion that the weight that might be supported by a pneumatic tyre was immaterial, provided the tyre contained, or had at its disposal, a sufficient volume of air in proportion to the weight supported.

As far back as 1913 Mr. Nuttall, in a contribution to the *Financial Times* and *Commercial Motor*, advocated the use of pneumatic tyres for motor-'buses, and showed, in those far-off days, when the idea was considered fanciful in its application, the possibility of successfully equipping such vehicles, providing the air volume was proportional to the weight.

Since those days, of course, the "Giant" had come forward, with high air volume, and successfully achieved what was considered an impossibility.

The speaker asked whether the author agreed that it was not necessary to retain the big volume of air in expensive large tyres, but that the same result would be obtained if the additional volume of air was contained in an air tight disc-wheel and connected to the tyre by means of air passages, the whole being inflated to the desired pressure through a valve fixed in the disc wheel? The speaker contended that the same results would be obtained from such a combination as was now obtained from the largest tyres in use, without the latter's enormous expense and lack of vehicular stability.

The speaker was of the opinion that the failure of tyres was due to the continued increase of pressure that took place inside a tyre—due to its continual deformation—that could the pressure be kept more constant, there was no more reason why a tyre should burst when travelling than when stationary. To this continual hammering of internal pressure was due the failure when a vehicle was undertyred. On the other hand, herein was the secret of the success of the larger tyre—the air pressure remaining more constant—and the same success would be derived from the use of the combination mentioned above.

The idea approaches the tyre question from an entirely new angle, and, the speaker contended, should make the equipping of motor-'buses and lorries, to say nothing of its application for ordinary car work, but a simple matter.

Mr. E. B. Killen said he thought every person in the motoring world would admit that the most important advantage which any tyre could have was good shock-absorbing qualities, combined with long life, and if a tyre, whether inflated or non-inflated, had not good shock-absorbing qualities, it was useless. In his opinion all tyres in the future, whether inflated or non-inflated, would have abnormal "give" (or shock-absorbing qualities) in road contact up to and over 1 in. as and when required, instead of only about ½ in. as in existing types of inflated tyres. If tyres were manufactured to "give" in road contact up to and over 1 in., then all road inequalities up to and over 1 in. would be absorbed, and such tyres were badly wanted at the present time, because of the shocking state of the roads. In fact tyres which were efficient before the war when the roads were good, are now inefficient when the roads are bad. It is impossible for existing solid rubber band tyres to "give" in road contact more than about ⅛th of an inch, and, therefore, the existing types of solid rubber band tyres were practically useless for shock absorbing purposes. The all-important and vital question of to-day was, how can tyres be manufactured to "give" in road contact up to and over 1 in. and run long mileages?"

Mr. A. Marshall Arter, F.S.E., A.M.Inst.C.E., Vice-President, in proposing a vote of thanks to the author, said that the first pneumatic tyre he saw was on a push bicycle, the tyre was held on the rim of the wheel by means of a strip of canvas wound round the tyre and the rim.

The function of pneumatic tyres were as follows:—

1. *Comfort:* at high speed on indifferent road surfaces;
2. *Safety:* to provide a sure grip on the road, particularly when accelerating, braking and cornering;
3. *Reliability:* good protection must be provided to the air container;
4. *Durability:* long mileage is called for and failure should be due only to fair wear and tear;
5. *Handiness:* to be reasonably easy to fit on and take off rim;
6. *Efficiency:* absorb a minimum amount of engine power.

Skidding depended a great deal on the weight distribution of the car when under running conditions, and the length of the wheel bases. This in conjunction with rubber studded tyres with some cars was sufficient. Skids were often the fault of the drivers. With reference to putting patches on inner tubes, the best method was first to clean the tube surface with petrol where the patch was to be fixed, then rough up with a file card, and solution the tube and patch in the ordinary way.

If the tube were roughed up first and then cleaned with petrol, some foreign matter was rubbed into the roughed surface of the rubber, and by cleaning with petrol the sharp edges of the roughed surface were dissolved, thus reducing the hold of the new rubber making the joint.

THE AUTHOR'S REPLY TO THE DISCUSSION.

The **Author** thanked the Vice-President and meeting for the kind reception given his paper, and associated himself with one of the speakers in expressing gratitude to the Society of Engineers for the opportunity given for this discussion of motor tyres. He expressed his indebtedness, for help with the illustrations, to Mr. H. Budden, Messrs. D. Bridge & Sons, Ltd., Mr. A. Mathern, and several tyre manufacturers.

The Author's experience was that punctures and bursts due to road usage, if not quite so prominent a feature of the pneumatic tyre as, say, fifteen years ago, were still largely responsible for poor mileages. He agreed that defective valves caused the ruin of many tyres and attributed much responsibility to the European valve which, in his opinion, contained an excessive number of small parts. The American type of valve held an advantage in this respect. The faulty fitment of tyres to the rims, and neglect to cleanse the interior of covers prior to insertion of the inner tubes, were still, unfortunately, common causes of the untimely collapse of many tyres.

The equipment of Royal Air Force tenders and cars in the war was twin 920 × 120 tyres on each rear wheel, with singles of the same size on the front ; single tyres of large cross-sectional size were never used, and the Author was not, therefore, enabled to make a comparison of "giants" *versus* "twins." He was able to say, however, that notwithstanding the harsh treatment meted out to the twin tyres (overloading and high speeds being unavoidable), the latter rendered good service on the average, and stoppages due to tyre trouble were remarkably few. He would recommend the same equipment in cases where urgency and some degree of certainty in reaching one's destination in schedule time were factors of more importance than that of costs.

The Author's contention that a perfectly plain tyre was superior to one of the rubber anti-skid type was based on his own experience. He, of course, assumed that the quality and quantity of materials used would be the same in each case, without which condition no fair comparison could be made. The smoother the tread of the tyre the less the friction generated in running, and also the less aptitude to pick up nails, flints, and similar obstacles on the road. The average motorist liked the appearance of a "fancy tread" tyre, and in that fact, coupled with the manufacturer's own desire for something distinctive, lay the explanation of the present day popularity of rubber anti-skid tyres.

As to the steel-studded tyre, the metal projections penetrated the layer of slime, and slipping was reduced, though not arrested by any unevenness existent in the surface of the street. The purely rubber tyre, whether "fancy" or plain, never got to grips with the street proper, but slid on the greasy surface, and, to this extent, was inferior to the steel-studded tyre. It was not claimed that the advantage was anything but small, but, in view of the object aimed at, *i.e.*, the prevention of accidents, there was still a case for the steel-studded tyre. The Author agreed that the latter in every other respect was a failure.

It was correct to say that the cushion of resilient rubber laid between the tread and the casing conformed to road stress. Years ago, when the cushion had not been thought of, the tread suffered severely by its tautness and want of flexibility, and the casing became easily fractured. A certain amount of lateral wear of the tyre occurred when the wheel bumped on the ground, but such wear did not affect mileage to any serious extent. The first condition to success was the strength of the casing, granted which the ultimate mileage depended upon the treatment given the tyre during its life, the luck of the tyre in escaping its numerous enemies on the road, and, finally, the durability of the tread. That the latter condition properly took last place was demonstrated by the high percentage of tyres scrapped before the treads were worn out.

The spare wheel was certainly the surest and, at the same time, the quickest means of overcoming tyre trouble in the progress of a journey. The time occupied in the repair of a tyre depended upon the form of job executed. The fitment of a canvas plaster to the cover and of a surface patch to the inner tube could be carried out within forty minutes, but a permanent (vulcanised) repair might occupy nearly a week. Dry graphite was a useful rust-preventive for rims, and should be rubbed in whenever the opportunity arose. The Author thought that rustless rims would greatly improve the modern British car.

The Author expressed regret that he could offer no opinion on the pneumatic wheel described, which, however, appeared to be of a most interesting type.

In theory and in practice the success of a pneumatic tyre depends upon the volume of air contained within the tyre being proportionate to the weight carried. The "giant" tyre may, however, be a failure, owing to the heavy cost involved in its production, and, subsequently, in its upkeep. The same remark applied to a pneumatic disc wheel of the type described. It was pointed out that even the ordinary disc wheel too often errs on the side of heaviness, and if any weight were to be added the result might not be satisfactory. Otherwise there was no objection to the principle of the air chamber as a means of providing increased resiliency without effecting a corresponding increase in the cross-sectional size of the tyre.

So far as cars of ordinary weight were concerned the Author did not know that there was any general dissatisfaction with the resiliency of modern pneumatic tyres. When, however, the case of heavy vehicles ordinarily equipped with solid tyres was considered, the circumstances were different, and hence the experiments that were being made with giant tyres.

Given an even (ground) surface, the pneumatic tyre was superior to the solid tyre, primarily because of the increased cushioning effect obtained. Other advantages such as the reduced weight and contact surface of the pneumatic tyre would be apparent.

The Author concurred with the statement that skidding, or more correctly, side-slip, was often influenced by chassis design, and that some makes of cars were, therefore, more susceptible to this form of danger than others. Apart from the chassis, landaulette, or other types of top-heavy bodies added considerably to the risk referred to. The advice given concerning surface patches to inner tubes was sound. Patches of this description, however, contrived to take away from the snug fit of the tube within the cover, and, in ordinary circumstances should be substituted by vulcanised repairs at the earliest opportunity.

THE PHYSICAL PROPERTIES OF CLAY.

[THIRD PAPER.]

By ALFRED S. E. ACKERMANN, B.Sc. (Engineering) Lond., A.C.G.I., M.Cons.E., A.M.I.C.E., M.R.S.I.

This paper deals with the results of 49 experiments (Nos. 210 to 258 inclusive) in continuation of the research work begun in 1917 and recorded in the papers presented to the Society in March, 1918, and October, 1919.*

It is gratifying to be able hereby to acknowledge a second grant of £30 from the Dixon Fund made by the Senate of the University of London in 1920, for apparatus with which to continue the work. It so happens that the first grant is not yet exhausted, so it will be realised that the research is not expensive as regards expenditure of money—the same cannot be said as regards time and patience.

Dealing with the experiments more or less in chronological order, No. 210 was to determine whether, and if so to what extent, the pressure of fluidity would be affected by boiling some of the clay. The hypothesis that each particle of clay may be surrounded by colloidal matter was mentioned at p. 220 of Paper II., and as some colloidal matter is of an organic and jelly-like character, it was thought that by boiling a quantity of the clay, allowing it to settle, decanting the clear liquid, and evaporating this, that some information might result. For this purpose about 2·5 kilos of clay containing about 25% of water were thoroughly mixed with a bucketful of tap water and placed over a

---

* In spite of much care the P.D. was at work again in paper II., consequently the following corrections should be made :—

At p. 199, fifth line from the bottom, for p. 2 read p. 197.

At p. 201, two-thirds down, read :—

$$= p_n - f \tan \alpha$$
$$= p_n - \mu p_n \tan \alpha$$
$$= p_n - 9{\cdot}47 \sqrt{p_n} \tan \alpha$$

and for p' on this page read p.

At p. 210 delete the asterisk following the heading, " ROLLED SPECIMENS."

At p. 213, line 11, for p. 20, read p. 210.

At p. 242, the first two equations, read :—

$$P \sin \alpha + F \cos \alpha = \frac{W+w}{4}$$

$$P \sin \alpha - F \cos \alpha = \frac{W-w}{4}$$

At p. 243, fourth line from bottom for Pn read p.

At p. 259, penultimate line, for p. 226 read p. 237.

gas fire. It was kept boiling for two hours on February 14th 1920, and was then left to settle till February 28th. There was then a layer of clear water on top of only 4 or 5 cms. thick. This was poured off and preserved. The rest was stirred, half poured into a second bucket, each filled with tap water, both stirred, and both boiled for 2½ hours, and again stood to settle. After some time about half a bucketful of nearly clear water was decanted from each, and the remaining half bucketfuls of slip were put together in one bucket, stirred and set to dry on an anthracite stove. By April 4th, 1920, it had dried until it contained only 31% of water, being frequently stirred during this period so as to get the resulting clay as uniform as possible.

About 4,000 c.c. of the water decanted on February 28th were set to evaporate in a new enamelled iron bowl. This ultimately dried (at a temperature of about 180° F.), leaving only a very thin layer of matter on the bottom having a strong red-brown or chrome colour. On being left a few days in the workshop it had apparently absorbed some moisture, and was then (April 11th) sticky and viscid to the touch, more like a thin layer of very viscous golden syrup than glue. On adding about 2·5 c.c. of water the colour became that of yellow ochre, and the matter has been kept.

The boiled clay was well puddled, and put in the tin 92 mm. in diameter by 210 cms. deep, and a penetration experiment (210) made on it with the 37 mm. Duralumin disc. The first load was 1,218 grams, and the eighth 3,878 grams, the increments being added every 10 minutes. The penetration was then 125·5 mm. On increasing the load to 4,178 grams the penetration had increased to 189 mm. in 10 mins., and consequently the pressure of fluidity appeared to be 389 grs. per sq. cm., but as the disc was so large in comparison to the containing tin, Exp. (211) was made under the same conditions, but with the 26 mm. disc. In this case the pressure of fluidity was 286 grs. per sq. cm., there being 31% of water in the clay, and the temperature being 58° F. in both cases.

Exp. (212) was made under the same conditions, but with the 18 mm. disc, and the pressure of fluidity was 279 grs. per sq. cm., differing only a little from the result of Exp. (211). A week later the same clay contained only 28·5% of water, and on making Exp. (213) with the 18 mm. disc and temperature of 55° F., the penetration was only 9 mm. with a load of 1,061 grs., while a load of 1,361 grs. gave a penetration of 104 mm., and the pressure of fluidity was thus no less than 534 grs. per sq. cm.

On referring to the pressure of fluidity curve at p. 58 I. for the clay before boiling, and before it had been allowed to become air-dried, it will be seen that for 31% of water the pressure of fluidity was 380 grs. per sq. cm., and for 28·5% of water it was

695 grs. per sq. cm. These results show a marked decrease of the pressure of fluidity due to the boiling, viz., of 26·3% and 23·2% respectively.

Exps. (214 and 215) were to determine the coefficient of friction of the boiled clay, and gave the following results, the apparatus being the double-surface one described at p. 202, II., and the water contents 28·5% :—

Exp. No.	Normal pressure pn between clay and surface of wooden slider, grs. per sq. cm.	Friction, f in grs. sq. cm.	Coef. of friction. μ
214 ...	15·47	29·3	1·89
214 ...	15·47	28·7	1·86
215 ...	37·95	41·8	1·10

Flow of Clay from under a Disc when the Pressure of Fluidity has been reached.—Some consideration has been given to the above matter. A tin 90 mm. was filled with clay containing about 27% of water, and the 26 mm. disc was forced into this by hand to form a vertical hole in the clay. A layer of clay was rolled out on a board, and powdered laundry blue was scattered on it ; the layer of clay was then rolled up so as to form a kind of " Swiss roll " a little less than 26 mm. in diameter. This was inserted into the hole in the clay in the tin so as to fill it completely The 26 mm. disc was forced by hand through the clay ; the bottom of the tin removed, to get out the disc without withdrawing it, and the clay was left to dry slowly in the tin. When dry the clay, in the form of a thick cylindrical tube, was easily removed from the tin and sawn through the axis of the cylinder so as to give a vertical section. The " blued " clay was in the form of a uniform lining (about 5 mm. thick) to the hole made by the disc.

If d is the diameter of the disc and its penetration h, then the volume of the clay completely displaced is $\frac{\pi}{4}d^2h$. If D is the external diameter of the lining formed by the displaced clay, then, as the volume of the lining must be equal to the volume of the displaced clay—

$$\therefore \quad \frac{\pi}{4}(D^2 - d^2)\,h = \frac{\pi}{4}\,d^2h$$

$$D^2 = 2d^2 \text{ and } D = d\sqrt{2} = 1{\cdot}414\,d$$

and the thickness of the lining is $\frac{D-d}{2} = 0{\cdot}207\,d.$

In addition to the completely displaced clay, there will be a certain quantity below the plane of the disc which is only partially displaced.

While the disc is penetrating the clay, the latter flows approximately horizontally and radially from under it, and it is probable that, owing to the adhesion of the clay to the under surface of the disc, the maximum lateral or radial velocity of the clay occurs on a plane a little below the disc, and that this lateral velocity decreases the further the horizontal plane considered is below the one at which the maximum velocity occurs. Ultimately there must be a plane below the disc at which there is no lateral or other movement, *i.e.*, where the clay is undisturbed by the penetration of the disc above it. Suppose the depth below the disc at which the clay is undisturbed is h_a, which will be constant for any particular condition of the clay; that the velocity of penetration of the disc (when fluidity is reached) is v_d; that the maximum horizontal and radial velocity of the clay relative to the vertical cylindrical surface containing the edge of the disc is v, and that the mean ditto is v_m, then the area of the curve of radial velocity on a space base h_a long must be equal to $h_a\, v_m$.

In the time t, the volume of clay completely displaced is—

$$V = tv_d \frac{\pi}{4} d^2$$

Disregarding the partially displaced clay below the disc, which is probably only a small quantity—

V is also $= v_m\, \pi d\, h_a t$, for the clay is discharged through the annulus d in diameter, and h_a in height, this annulus moving down with, and at the same speed as, the disc.

$$\text{Hence} \quad tv_d\, \frac{\pi}{4} d^2 = v_m \pi d h_a t$$

$$\therefore \quad v_m = v_d \frac{d}{4\, h_a} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

or $v_m\, h_a = v_d \dfrac{d}{4}$ in which v_d and d are known.

v_d has been found by experiment to be about 1 cm. per min., and h_a must be determined experimentally. Fortunately, Lt.-Col. E. R. Lordly, M.C.E. (Cornell), F.S.E., has done some experimental work to determine the disturbance of clay by piles. He placed layers of iron filings in clay containing about 26% of water, and then forced in piles, having different ends, and took skiagrams of the experiment at two stages. These are published at p. 187 of his paper, " The Lateral and Vertical Pressure of Piles in Clay," read before the Society of Engineers, on October 4th, 1920, and show that the disturbance below flat-ended piles extends for a depth about equal to twice the diameter of the pile, *i.e.*, $h_a = 2d$.

Inserting this in equation (1), when $v_d = 1$ cm. per min., we have

$$v_m = v_d \frac{d}{8d} = \frac{v_d}{8} = \frac{1}{8} \text{ cm. per min.}$$

Thus v_m is independent of d.

Remembering the definition of v_m, on consideration it will be seen that as the clay flows radially from under the disc its velocity will decrease owing to the larger and larger cylindrical area concerned, and when the diameter of this cylindrical area is D, the lateral flow will have ceased. Hence the mean lateral velocity of the clay between the vertical cylindrical surface containing the edge of the disc and the corresponding cylindrical surface of diameter D is $\frac{v_m}{2}$.

Exps. (218-223) were made also for the purpose of finding out what happens under a sinking disc. An enamelled iron bowl about 18 cms. diameter was surcharged with clay for a height of 14 cms. There was thus a cylinder of clay 18 cms. diameter and 14 cms. high above the rim of the bowl. The clay contained about 25% of water. The 37 mm. disc was used in all the experiments, and the penetration limited to 13 cms. or less. A taut wire was used for slicing off at the rim the surcharged clay and for making a vertical section through the thick annulus of clay as far as the vertical hole made by the disc. The vertical cut was then carefully opened so as to expose the hole and the disc for examination. The disc was loaded to produce the pressure of fluidity. These arrangements worked well. In Exp. (218) the 37 mm. disc, had a layer of clay about 1 mm. thick smeared on to its under surface, which was then pressed firmly on to a quantity of white beads each 2 mm. in diameter. 242 beads stuck to the disc forming a complete surface of beads one bead thick. The disc was then loaded in the usual manner, and the penetration stopped at 105 mm. On opening up in the manner described, 7 beads were found in the side of the hole within one cm. of its top. The remaining 235 were undisturbed from their original position under the disc.

Exp. (219) was made under like conditions, but with a complete layer of beads each 3 mm. diameter, and the penetration was 110 mm. On opening up, three beads were found in the side of the hole, and the rest (121) were undisturbed under the disc.

Exp. (220) was made under like conditions, but with a layer of 33 beads each 5·5 mm. diameter. The penetration was 130mm. One bead was found in the side of the hole and about 1 cm. from the bottom of it. The remaining 32 were undisturbed.

In Exp. (221) 20 beads 7 mm. diameter were used, and the penetration was 125 mm. The sides of the hole were grooved by some of the beads projecting slightly beyond the edge of the disc, but for all this the whole 20 were found undisturbed after the experiment.

In Exp. (222) instead of a single layer of beads, three layers were used with layers of clay between them. The first layer of clay was on the disc, and adhering to this was a layer of 20 beads, each 7 mm. diameter. Then a layer of clay, then the middle layer of 23 5·5 mm. beads. Then a third layer of clay and the third layer of 10 5·5 mm. beads. The whole formed a rough " hemisphere " 37 mm. diameter and 22 mm. high, each layer of clay being about 1·5 mm. thick.

The " cheese " of surcharged clay in this experiment was 15 cms. high. A hole was scooped out of the centre of its top into which the hemispherical " point " just described was fitted so that at the start the disc was flush with the surface of the clay. The disc was loaded, and the speed of penetration was about 4 cms. per minute. The penetration was 95 mm., and there was some flattening of the " cheese " itself. On opening up the hole was found to be heavily grooved by some of the 7 mm. beads. One 5·5 mm. bead was found in the side of the hole, 4 cms. from the top of it. The three layers of beads were plainly seen, and apparently undisturbed, though the vertical height of the " point " was reduced from its original 22 mm. to 18 mm. On removing the beads layer by layer it was discovered that the bead found in the side of the hole had come from the apex layer.

As it appeared that this built-up " point " had acted like a masonry structure, and interfered with the free movement of clay surrounding the beads, Exp. (223) was made. In this case a parabolical point of plain clay was formed on the disc, 34 mm. high and 37 mm. diameter at the base. A piece of black cotton was wound round the base, the ends touching each other, but not being knotted. 6 mm. above this was a ring of scarlet cotton. 6 mm. above this was a ring of purple cotton. 6 mm. above this was a ring of blue cotton, and, lastly, a ring of white cotton.

At the extreme point one 5·5 mm. bead was pressed into the clay for about two-thirds of its diameter.

A hole to fit the point was scooped out of the surcharged clay, the point inserted, and the surrounding clay pressed firmly on to it. The disc was then flush with the top of the surcharged clay. The load placed on the disc caused a speed of penetration of 2·1 cms. per minute.

On opening up, the cottons were found in this order : Black, scarlet, purple, and blue. The first-named three were within 2 cms. of the top of the hole. The blue about 4·5 cms. The white was partly under the disc. Penetration 105 mm. Hence the black, scarlet, purple, and blue pieces of cotton had not moved from their original positions.

The bead was found 13 mm. below the disc measured to its centre, and slightly away from the centre of the disc. Thus the " point " appears to have crushed from 31 mm. to 13 mm.

Friction or Adhesion of Clay to the cylindrical Surface of a Pile.

This was dealt with in Paper I., but in discussing the matter with Prof. C. V. Boys he suggested that it would be more satisfactory if the support of the clay on the end of the pile could be completely eliminated. Hence Exp. (217) was devised. An enamelled iron bowl about 18 cms. diameter was surcharged with clay to a height of about 9 cms. about its rim, a cylindrical wooden pile 18 mm. diameter being placed horizontally in the surcharged clay so that there was 35 mm. of clay above the top side of the pile, and 35 mm. between the lower side of the pile and the rim of the bowl. The clay was squeezed well into contact with the pile, and the top flat surface of the clay was loaded uniformly with 4·54 kilos placed in another enamelled iron bowl resting on the clay. Wet rags were placed round the surcharged clay to prevent it from drying. Both ends of the pile protruded beyond the clay ; the longer one was provided with a hook and a pointer arranged over a fixed board with a zero mark on it. One end of a spring balance was attached to the hook in line with the pile. The other end of the spring balance had a cord fixed to it, which was taken over a pulley, and had a weight attached to its other end. By increasing this weight the pull of the spring balance was increased, and its reading was the pull on the pile.

The diameter of the surcharged clay was 18 cms., and this was also the length of the pile in contact with the clay, which contained about 25% of water. The temperature in the workshop during the experiment varied from 64° F. to 73·5° F.

Time.	Total pull on pile.	Movement of the pointer from zero.
18/7/'20.	Grams.	mm.
1.30 p.m.... ...	1,350	0
3.15 p.m.... ...	1,350	0
3.25 p.m.... ...	3,030	0
7.40 p.m.... ...	3,000	0·5
7.43 p.m.... ...	4,000	0·5
10.34 p.m.... ...	4,000	0·5
10.36 p.m.... ...	5,600	0·5
19/7/'20.		
9.00 a.m.... ...	5,600	0·5
9.13 a.m.... ...	7,600	0·5
10.24 p.m.... ...	7,450	2·0
10.27 p.m.... ...	7,600	2·0
20/7/'20.		
7.30 a.m.... ...	7,500	2·0

When increasing the pull beyond 7,500 grs., the load was by accident increased to 10,000 grs. for a few seconds, and then reduced to 9,000 grs., and while the apparatus was being adjusted the pile pulled out, leaving a clean hole and clean pile. Hence the friction was at least $=\dfrac{9{,}000}{\pi 1 \cdot 8 \times 18}=88 \cdot 3$ grs. sq. cm. This experiment shows that there was no " creep," such as there is in the case of a true liquid like pitch, even though the test pull was at least $\dfrac{7{,}600}{10{,}000}=76\%$ of the " breaking " pull.

Effect of an artificial Head of Clay on its Pressure of Fluidity.— Exps. (224-230) were for determining the above. For this purpose seven discs of sheet lead, nearly as large in diameter as the bucket, were made, and in the centre of each was a hole 43 mm. diameter through which to pass the disc for determining the pressure of fluidity.

Exps. (224-5), without any artificial head showed that the pressure of fluidity was 1,320 grs. sq. cm., the water content being 25%. The total weight of the seven lead discs was soon found to be insufficient, so a wooden disc 44 mm. thick was made to fit on top of the lead ones, and a considerabls weight was placed on this. Thus the total weight on the top surface of the clay was as follows :—

No. of Exp.	Total wt. on surface of clay in grms.	Weight in grms. per sq. cm. of top surface of clay.
224	0	0
225	0	0
226	4,716	7·3
227	9,802	15·2
228	18,501	28·6
229	0	0
230	41,583	64·4

All seven experiments were with the 37 mm. disc.

The summary of the results is :—

No.	Total statical head, grs. sq. cm.	Increase of statical head due to added load, grs. sq. cm.	Pressure of fluidity, grs. sq. cm.	Increase of Pressure of fluidity, grs. sq. cm.	Increase of statical head, %	Increase of pressure of fluidity, %	Date, 1920.
224...	11·1	—	1,320	—	0	0	Sept. 5th
225...	33·6	7·4					
226...	41·0		1,320	0	21·8	0	
227...	48·8	15·2	1,347	27	45·3	2·05	
228...	56·3	26·7	1,173	81	90·2	7·4	11th
229...	29·6	62·4	1,092		0	0	11th
230...	92·0		1,173	81	211·0	7·4	12th

In Exp. (226) no difference due to the artificial head was noticed, except that the speed of penetration when the pressure of fluidity was reached was less than when the clay was unloaded.

The results of the seven experiments are somewhat irregular, *e.g.*, Exps. (224-5) gave the pressure of fluidity for the unloaded clay as 1,320 grs. sq. cm., while Exp. (229), which was also with unloaded clay, gave it as only 1,092 grs. sq. cm. For all this it is pretty obvious from these experiments that the *percentage* increase of the pressure of fluidity was very small compared with the *percentage* increase of statical head, but the actual increase of the pressure of fluidity in all three cases was greater than the actual increase of the statical head.

It is remarkable that in Exps. (228 and 230) more than doubling the load on the clay made no difference in the pressure of fluidity, and that over trebling (211% increase) the total head in the last experiment made an increase of only 7·4% in the pressure of fluidity.

Extrusion of Clay through Circular Orifices of different Diameters.—The extrusion apparatus described at p. 102, I., having failed for the reasons given at p. 213, II., an entirely new piece of apparatus for extrusion experiments was designed. This consists of a gunmetal cylinder, 24 cms. internal diameter, 17·7 cms. in height, about 5 mm. thick, and tinned inside. The bottom end is closed by a mild steel plate 12·5 mm. thick screwed into the cylinder and sweated. The top end is provided with a stout narrow flange and a mild steel plate 12·5 mm. thick, which is clamped to the flange by eight screw clamps. A gland is provided at the centre of the bottom plate to hold the orifice discs, which are all 50 mm. diameter, 3·5 mm. thick, and made of Duralumin.

The top plate, or cover, is provided with a pressure gauge, reading by pounds to 20 lb. per sq. in., a bicycle tyre valve, and a small set screw to release the air pressure when necessary. The joints are made with thin rubber sheet.

The apparatus is supported by a stand at a convenient height for cutting off the clay at definite times as it is extruded from the orifice.

The clay is packed into the container (as the cylinder is called) in the form of a sugarloaf, about 16 cms. high, covering the whole of the bottom, but *not* touching the sides. This is to avoid any effect which otherwise there might be due to friction or adhesion of the clay to the sides. The cover is then clamped on, and air is pumped into the space in the container not occupied by clay by means of a bicycle pump. The air pressure is maintained at any desired pressure by occasional pumping. The rod or filament of clay hangs vertically as it leaves the orifice and is cut off, at definite times, flush with the lower side of the orifice plate by means of a bent wire. The quantity extruded in any given time is weighed, and the result recorded.

Exp. (231) was the first with this apparatus, using the 20·2 mm. diameter orifice. The clay contained 25% of water. There was no discharge from the orifice when the air pressure was 350 or even 700 grs. sq. cm. Only 5 grs. were discharged in 10 mins. when the pressure was 1,070 grs. sq. cm., but with a pressure of 1,547 grs. sq. cm. the discharge was 50 grs. in 50 mins., and in a separate period of 500 mins. the discharge was 561 grs. =1·12 grs. per min.

In spite of the clay not being in contact with the sides of the container, the quantity of clay discharged during the first period of 5 mins. after an increase of the pressure has usually been considerably greater than during succeeding periods. This phenomenon was noticed in connection with the glass tube container and recorded at p. 214, II., but evidentlythe explanation there suggested is not the complete one.

On removing the cover after the air had blown through the orifice in Exp. (231), it was found that a large proportion of the original charge of clay was still in the container. The " sugar-loaf " was reduced in height about 50 mm., and was pierced by a rough vertical hole about 15 mm. diameter for most of its length, and opening out to 60 mm. diameter at the top. This formation was practically the same after each extrusion experiment that was continued (as was usual) until the air blew through the orifice.

As with 25% of water, the largest orifice and the maximum pressure the gauge would read, the discharge was only 1 gr. per minute, water had to be added to the clay, and after 1½ hours' puddling it was considered sufficiently uniform for another experiment. No. (232, was made with the 37 mm. disc, and the pressure of fluidity found to be 407 grs. sq. cm., the water content being 29%. Exp. (233) was an extrusion one with the 20·2 mm. orifice with pressure increased from 281 to 422 grs. sq. cm. As the results were irregular and pebbles were found which were large relatively to the 20·2 mm. orifice, it was decided to force the whole bucketful of clay through a potato masher so as to remove all pebbles and sand above the size (2·5 mm. diam.) of the circular holes in the masher.

The total weight of clay dealt with was 18·4 kilos, and this weight was found to contain 222 grs. of small pebbles and large sand, therefore the percentage of these in the clay before it was passed through the masher was 1·2%.

Exps. (234 and 5) were with the 37 mm. disc to determine the pressure of fluidity, which was found to be 298 grs. sq. cm., the water content being 29·5%.

Exp. (236) was to determine the friction of the clay while in the same condition. The temperature in the workshop was 58°F. The double surface slider (described at pp. 201-4 II), having a total area of 161 sq. cms. was used, and the following are the results :—

Total load on slider grs.	p_n the intensity of normal pressure on *one* surface of slider grs. sq. cm.	Pull on slider in grs.	Friction per sq. cm. *f*.	Coefficient of friction μ.
2,300	28·5	5,930	36·8	1·294
3,300	41·0	6,840	42·5	1·037
2,300	28·5	6,500	40·4	1·420
3,300	41·0	7,200	44·7	1·090
3,300	41·0	6,250	38·8	0·946
4,110	51·0	7,380	45·8	0·898

These results, like the earlier ones, show that the coefficient of friction is not constant, but decreases as the pressure of the clay on the surfaces increases.

Exps. (238-243) were all extrusion ones with different sized orifices. The results are given by the accompanying curves, but No. (238) is given in tabular form as typical and to indicate the relationship of the tabular results to the curves.

Attention is called to the 50% decrease in the discharge per min. during the period 10.09 p.m. and 10.50 p.m. compared with the discharge during the period 8.54 to 9.04 p.m., all the conditions being the same except that the orifice was plugged and the experiment stopped between 9.04 and 10.05 p.m. The water content was 29·5%, and the temperature of the workshop 57°F.

Time.	Pressure in grs. sq. cm.	Weight discharged in the period, grs.	Mean discharge in grs. per min.
p.m.			
7.54 ...	282	—	—
7.59 ...	282	1	0·20
8.03 ...	352	—	—
8.08 ...	352	3	0·60
8.10 ...	422	—	—
8.15 ...	422	9	1·10
8.20 ...	422	6	
8.25 ...	422	4	
8.30 ...	422	3	
8.32 ...	492	—	—
8.37 ...	492	29	4·3
8.42 ...	492	22	
8.47 ...	492	19	
8.52 ...	492	16	

Time.	Pressure in grs. sq. cm.	Weight discharged in the period. grs.	Mean discharge in grs. per min.
8.54 ...	563	—	—
8.59 ...	563	61	10·2 orifice plugged.
9.04½ ...	563	54	
10.05 ...	563	—	— orifice unplugged.
10.09 ...	563	—	—
10.14 ...	563	21	5·08
10.19 ...	563	28	
10.24 ...	563	29	
10.29 ...	563	26	
10.35 ...	563	25	
10.40 ...	563	25	
10.45 ...	563	30	
10.50 ...	563	24	
10.53 ...	633	—	—
10.58 ...	633	160	33·05
11.03 ...	633	151	
11.08 ...	633	182	
11.13 ...	633	168	
11.18 ...	633	225	—
11.20¼ ...	—	—	— the air blew through the orifice.

The increase of the discharge just before "blowing through" is probably due to the reduced cohesion or friction between the discharging clay and the self-formed hole in the clay in the container.

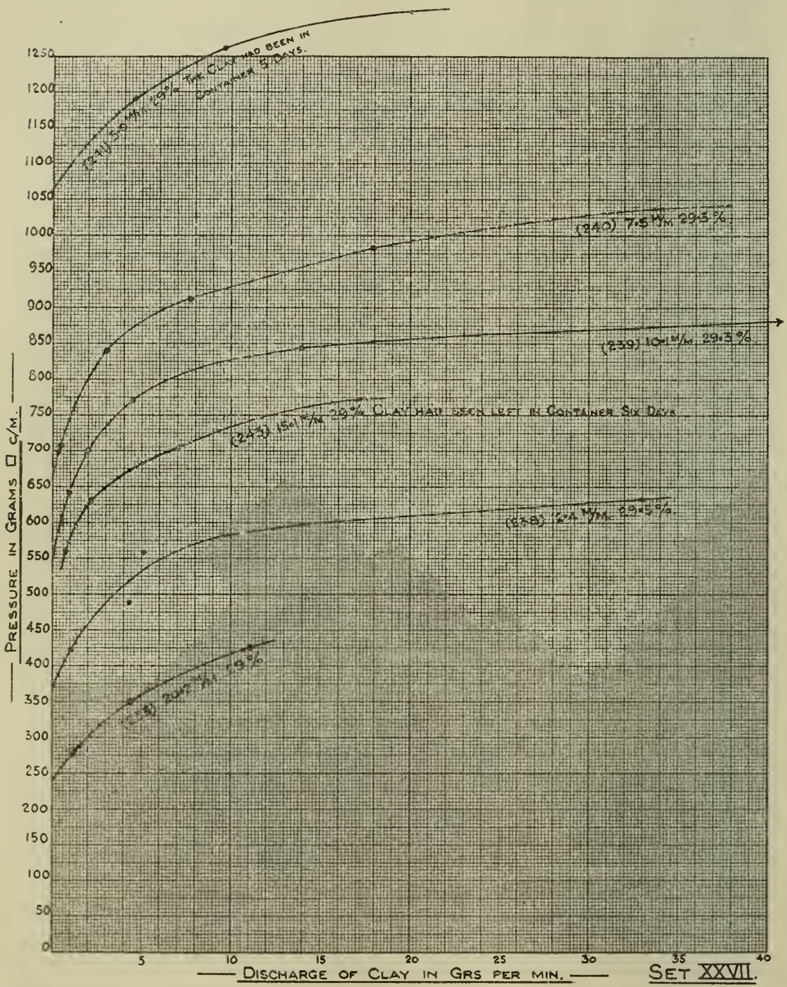
During Exp. (240) the 7·5 mm. orifice was plugged for a period of 7 mins. when the pressure was 984 grs. sq. cm., and this had no effect on the quantity discharged during the 5 min. period immediately following the unplugging. The orifice was then immediately plugged again and kept plugged for 12 hours and 2 mins. The pressure fell during this period from 984 to 773 grs. sq. cm. It was pumped up to 984 again, the orifice was unplugged, and the quantity then discharged in the immediately following 5 mins. was only 4 grs., while the mean quantity during the next 20 mins. was 57 grs. per 5 mins., and the mean quantity during the 20 minutes immediately preceding the 12 hours that the orifice was plugged was 88 grs. per 5 mins. The water content was 29·3%, the temperature 55°F. during the early part of the experiment, and 52°F. during the later. Otherwise all the conditions were constant. The decreased discharge after a long rest seems to imply a "setting" of the clay, or something of the nature of statical friction or cohesion, as distinct from dynamic friction.

In Exp. (241) with the 5·0 mm. orifice, and a pressure of 1,265 grs. sq. cm., the orifice was plugged for 2 hours 33 minutes, and the quantity discharged immediately thereafter was only 10% less than before or after.

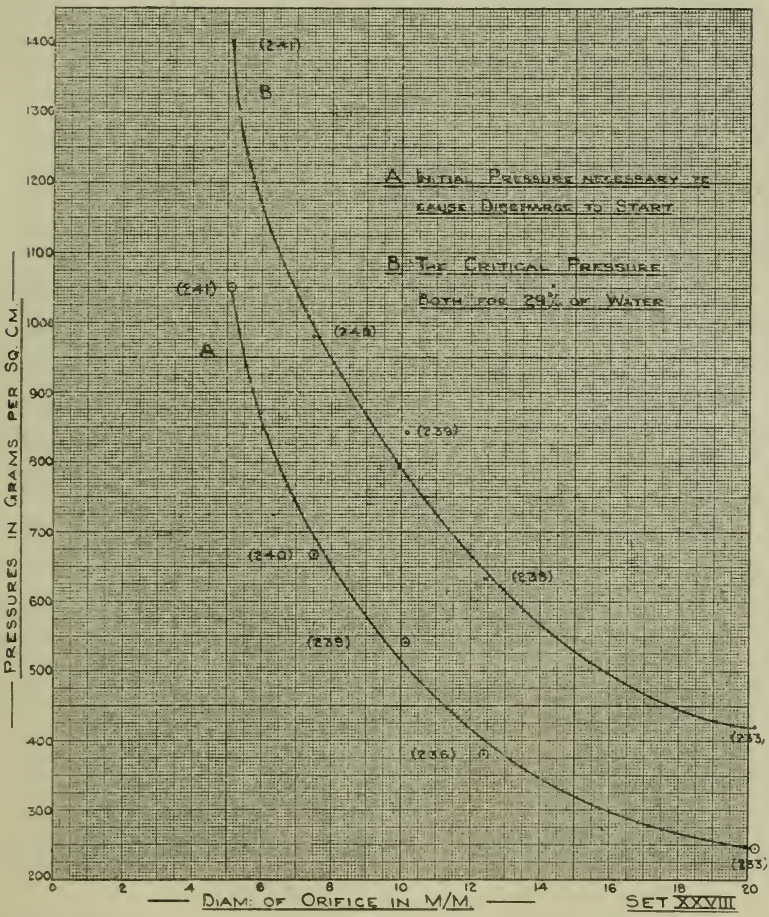
In Exp. (243) with the 15·1 mm. orifice, the water content was 29%. Several of the filaments discharged in 5 minutes weighed about 100 grs. The area of this orifice is 1·79 sq. cms., therefore the weight of a 100 gram filament pulling the clay through the orifice was equivalent to an addition to the air pressure in the container of $\frac{100}{1\cdot 79} = 55\cdot 7$ grs. sq. cm., so that when the air pressure was 773 grs. sq. cm., the weight of these long filaments was equivalent to an increase of $\frac{55\cdot 7}{773} = 7\cdot 2\%$ in the air pressure. It was exceptional for the filaments to be so long, and no correction for this effect has been made in any of the pressures used in plotting the curves. In one case in this experiment, within 12 minutes of the "blow through," and therefore rejected from the plotted results, the filament weighed 124 grs. Its cross section was 1·79 sq. cms. and its tenacity therefore 69·3 grs. sq. cm.

The curves forming Set XXVII. connect the pressure (ordinates) and the discharge in grams per min. It is seen that for any orifice the slope becomes much less as the pressure increases, *i.e.* as the pressure increases, the increase of discharge, for an equal increase ot pressure, becomes greater. In the cases of the curves for the 10·1 mm. and 12·4 mm. orifices this tendency for the curve to become horizontal is most marked, and thus in connection with the discharge of clay from an orifice there is exhibited a phenomenon analogous to that of the pressure of fluidity. There is one marked difference : the pressure, when the curve is nearly horizontal (which is called herein the critical pressure of extrusion) for a given orifice and water content is *not* the same for a different sized orifice, being greater for a smaller orifice. *E.g.*, the curve for the 7·5 mm. orifice is tending to become horizontal for a pressure of 1,025 grs. sq. cm., while that for the 10·1 mm. orifice is nearly horizontal at 900 grs. sq. cm., the water content being 29·3% in both cases. The difference of 125 grs. sq. cm. thus appears to be due to orifice resistance, for the ratio of the circumference to the area of a circle becomes greater as the circle gets less. Taking an extreme case : the critical pressure for the 5·0 mm. orifice appears to be 1,400 grs. sq. cm., and that for the 20·2 mm. orifice, 450 grs. sq. cm. The ratio of these is 3·1. The ratio of the circumference to the area of a circle is $\frac{4}{d}$. This in the case of the 5 mm. orifice is 0·8, and in the case of the 20·2 mm. one, practically 0·2. The ratio of 0·8 to 0·2 is 4, which is to be compared with the 3·1 above. Hence the ratio of the critical pressures does not appear to increase so fast as the other ratio.

It will be seen that the curve for the 15·1 mm. orifice is out of sequence with the others. The reason for this may be that the experiment was made after the clay had been left at rest in the container for six days, and the experiment was made without disturbing the clay, whereas in the other cases the clay had been puddled and put in a short while before the experiments.

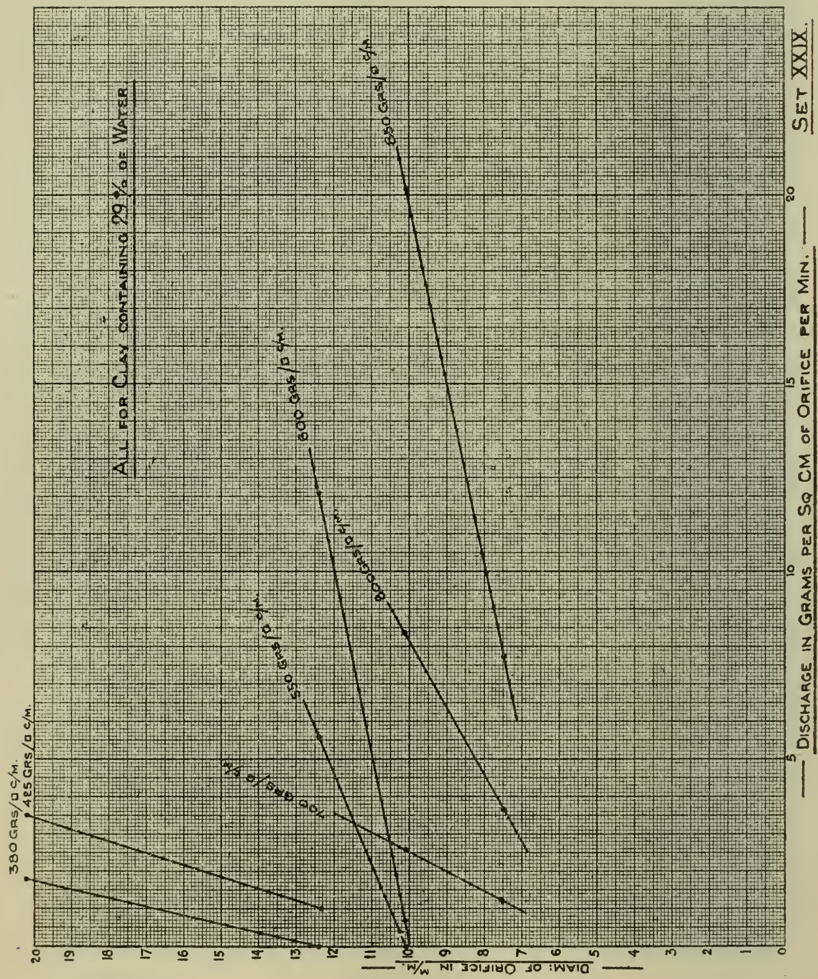


Another way of considering the results recorded by the curves forming Set XXVII. is to notice that for some given discharge, say of 10 grams per min., the 20·2 mm. orifice needed a pressure of 415 grs. per sq. cm., while the 10·1 mm. orifice needed a pressure of 830 grs. per sq. cm., *i.e.*, in this case the pressures are inversely as the diameters of the orifices. For the same discharge the 10·1 mm. orifice needed 830 grs. sq. cm. and the



7·5 mm. 930 grs. sq. cm. The ratio of these diameters is $\frac{10 \cdot 1}{7 \cdot 5} = 1 \cdot 35$, and the inverse ratio of the pressure is 930/830 = 1·12. The 12·4 mm. orifice needed a pressure of 635 grs. sq. cm. and the 10·1 mm. orifice 830 gr. sq. cm. The ratio of these diameters is 12·4/10·1 = 1·23, and the inverse ratio of the pressures is 830/635 = 1·31.

The curves have been exterpolated a short distance back to the ordinate representing no discharge, and the intersections



with this ordinate indicate considerable pressures before there was any discharge. Plotting these initial pressures, which were necessary to cause the discharge to start, as ordinates and the diameters of the orifices as abscissæ, we obtain curve A of Set XXVIII., which looks like an hyperbola.

Similarly curve B of Set XXVIII. connects the critical pressures of extrusion with the diameters of the orifices. This proves to be an hyperbola, its equation being $pd^{0 \cdot 833} = 5{,}408$, where p is in grams per sq. cm., and d is in mm.

Thus while the pressure of fluidity is independent of the diameter of the disc, the critical pressure of extrusion depends on the diameter of the orifice in the manner just stated.

Set XXIX. brings out clearly the effect of an increase of pressure on the rate of discharge *per sq. cm. of area* of the orifice. These curves are easily deduced from those forming Set XXVII. They connect the diameter of the orifice (ordinates) with the discharge of clay per sq. cm. of orifice.

Consider the three curves for the 7·5 mm. and 10·1 mm. orifices. When the pressure is 700 grs. sq. cm. the change from the smaller to the larger orifices causes the discharge *per sq. cm.* of orifice to increase from 1·15 grs. to 2·53 grs. (120% increase), but when the pressure is 800 grs. sq. cm. the corresponding increase is from 3·65 to 8·4 grs. sq. cm. (130%), while when the pressure is 850 grs. sq. cm. the increase is from 7·75 to 20·2 grs. sq. cm. (160%). Thus the clay behaved very differently from water, the discharge of which per unit of area of circular orifices is independent the diameter of the orifice.

Viscosity.—It seems probable that when the pressure of fluidity is reached the clay acts as a viscous fluid, and that consequently it should be possible to determine its viscosity from the results of the experiments with the discs.

Sir George Gabriel Stokes, Sc. D., F.R.S., calculated in 1850 the ultimate constant velocity that a small sphere would attain when falling in a liquid. This law was checked experimentally by others and confirmed. At least one experimenter used spheres 4 ins. in diameter, which are hardly small, but they may have been used for determining the viscosity of air.

Stokes's Law is—

$$v = \frac{2r^2 (s - s')g}{9\eta}$$

where v = the ultimate constant velocity of the falling sphere in cms. per sec.

r = the radius of the sphere in cms.

s = the density of the sphere in grams per c.c.

s' = the density of the liquid in grams per c.c.

g = acceleration due to gravity = 981 cms. per sec. per sec.

η = the viscosity in C.G.S. units, *i.e.*, in dyne-secs. per sq. cm.

Stokes called attention to the fact that the resistance opposed to the sphere varies *not* as its surface but as its radius. This leads us to try whether the law may not with some modification be applied to discs sinking in clay when the pressure of fluidity has been reached.

If we multiply both the numerator and denominator of the expression for v by $\frac{2}{3}\pi r$, we get $v = \frac{\frac{4}{3}\pi r^3 (s - s')g}{6\pi r\eta}$

$$= \frac{\textit{weight of sphere} - \textit{weight of equal volume of the liquid}}{6\pi r\eta}$$

In the case of a disc there is no volume, and even in the case of a sphere the load that has to be put on it in order to produce the pressure of fluidity of clay is so great compared with the weight of an equal volume of clay, that the latter may be omitted without introducing much error.

Hence we expect that the velocity of a disc in clay when the pressure of fluidity has been reached may accord with $v = \frac{(\textit{load in grams on the disc})\, g,}{6\pi r\eta}$ or $\eta = \frac{(\textit{load})\, g,}{6\pi r v}$ where r is the radius of the disc.

For a particular disc $\frac{g}{6\pi r} = \text{const.}$

Thus for the 1·8 cm. disc and c.g.s. units, $\frac{g}{6\pi r} = 57{\cdot}76$
,, ,, 2·6cm. ,, ,, ,, ,, = 40·00
,, ,, 3·7 cm. ,, ,, ,, ,, = 28·15
,, ,, 6·3 cm. ,, ,, ,, ,, = 16·53

The velocity of penetration could not be accurately determined by the method described in Paper I. for measuring the penetration at the end of each period of 10 mins., and at that time no particular importance was attached to that velocity except that when the pressure of fluidity was reached it appeared to be about tenfold what it was before. Hence we cannot expect regular or reliable results if those velocities are used to determine the coefficient of viscosity.

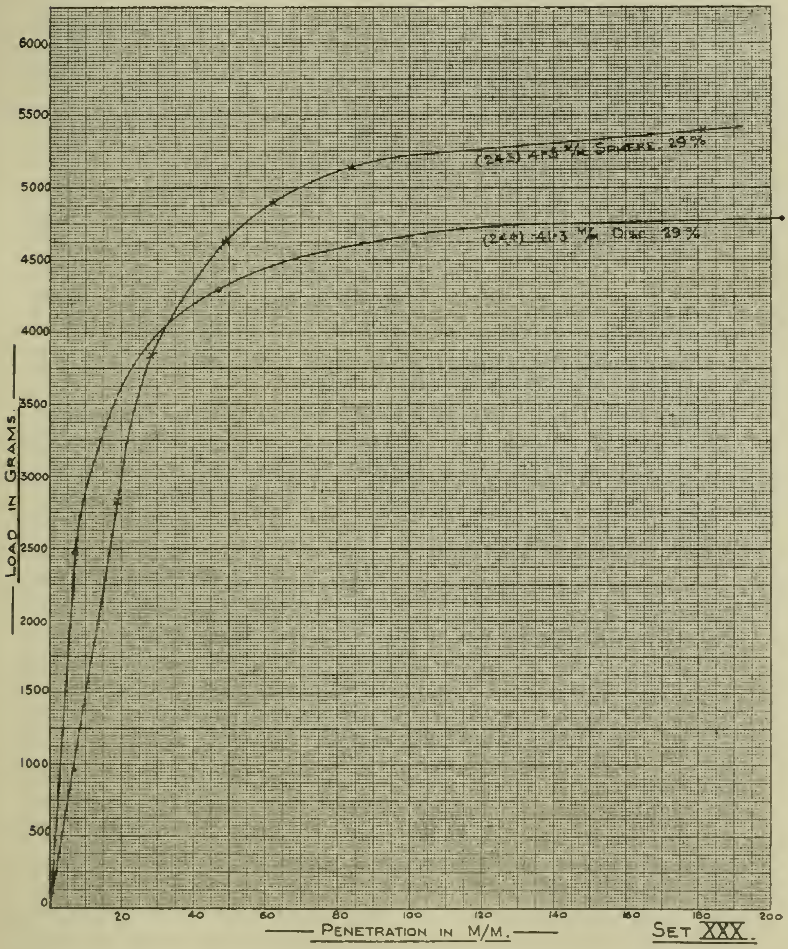
Exps. (87-9) were particularly carefully made [using the old method (callipers) for measuring the penetration] with clay containing 29% water. They gave the following results :—

No.	Diam. of disc, cms.	Velocity in cms. per sec.	Viscosity in C.G.S. units.
87 ...	6·3	0·149	$20{\cdot}4 \times 10^6$
88 ...	3·7	0·180	$9{\cdot}77 \times 10^6$
89 ...	2·6	0·179	$7{\cdot}82 \times 10^6$

These are certainly irregular, but appear to be of a reasonable order of magnitude, for Kaye and Laby, in their " Physical and

Chemical Constants" (1911), give the viscosity of shoemaker's wax at 8° C. as $4 \cdot 7 \times 10^6$.

In order to determine more accurately the speed of penetration an autographic apparatus was designed, making use of a clock-driven drum belonging to a recording vibrometer. This drum, being only 90 mm. diameter and 120 mm. high, a tin oil can 217 mm. diameter and 250 mm. high was obtained, and to its bottom a tin 90 mm. in diameter and 107 mm. high was soldered mouth downwards so as to slip over the clock drum. A pencil carrier was arranged to slide vertically so that its pencil could



draw a vertical line on the large drum when the latter was at rest. To the lower part of the pencil-carrier a silk thread was attached. The other end of this was fixed to the end of a light bracket 210 mm. long, which in turn was attached to the load-guide-rod of the disc. The silk thread was vertical, so that no guide pulleys were used. To the upper part of the pencil carrier another silk thread was tied, the thread taken over one pulley, and a counterweight hung on its free end to balance the weight of the pencil-carrier. The pencil was held against the paper on the drum by a light spring, and the total friction, including that of the pencil on the paper, was only 25 grams. The speed of the surface of the paper on the drum was approximately 4 mm. per minute. An attempt to make the clock drive the drum at about three times this speed failed, as then the moment of the friction of the pencil was too much for the clock, which was never meant for so large a drum. Even with the speed of 4 mm. per minute the time scale has proved somewhat irregular, and in Exp. (253) it was badly so, but fortunately this did not occur at the critical period, *i.e.*, while the rapid penetration took place. Hence a more suitable clock-drum should be used.

Before using this autographic apparatus it was thought it would be well to compare the penetration of a disc with that of a steel sphere of the same diameter (41·3 mm.), so Exps. (244 and 245) were made. The results were plotted and form Set XXX. The curves show that after the sphere had penetrated a little more than half its diameter it supported a larger load than the disc, so that while the pressure of fluidity as determined by the disc was 363 grs. sq. cm., the water content being 29%, it appeared to be 404 grs. sq. cm. if the maximum load on the sphere were divided by the maximum sectional area of the sphere, *i.e.*, by the same area as the disc. This small difference is probably due to the additional support given to the sphere by the adhesion of the clay to its lower hemispherical surface.

On removing the load-rod (which had been cupped at the end to fit on to the sphere), the hole in the clay made by the *sphere* was found to be smaller in diameter towards the bottom. It was estimated that the diameter of the smallest part was 25 mm., and that this occurred 150 mm. from the top, while the sphere was 41·3 mm. diameter, and its lowest point was 181 mm. from the top surface of the clay. The top hemispherical surface of the sphere in this and other experiments was always free from any contact with the clay.

Exps. (246 and 247) were similar ones made the next day with the 18 mm. disc and an 18 mm. glass sphere (from a soda water bottle). The water content was still 29%. The pressure of fluidity by the disc was 458 grs. sq. cm., and by the sphere

419 grs. sq. cm., *i.e.*, in this case the sphere supported *less* than the disc. The hole in the case of this sphere was also tapered.

It was thought that more work should be done to compare the action of discs and hemispheres, especially by means of the autographic apparatus, so MM. The Hoffmann Manufacturing Co., Ltd., were again communicated with, and they kindly presented three more steel balls, 37·4, 25·5, and 18·0 mm. in diameter respectively. Exps. (249-258) were then made with the autographic apparatus, and the resulting autographic curves form sets XXXI. to XXXIII.

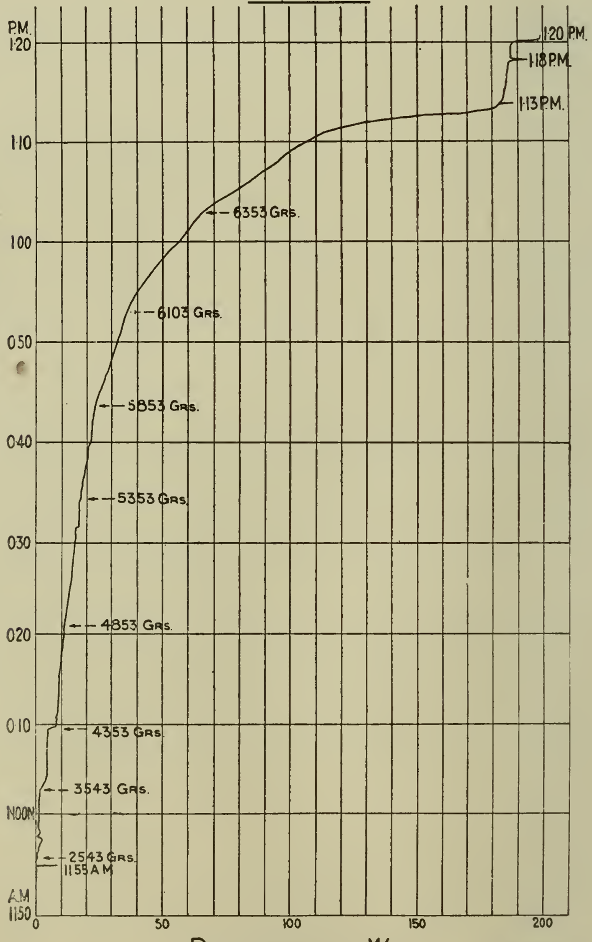
The following are the results as regards the pressure of fluidity. In all cases the spheres were of hard, polished steel, being, in fact, for ball bearings, while the discs were made of Duralumin 1 mm. thick :—

No.	Sphere or Disc.	Diam. mm.	Pressure of fluidity, grs. sq. cm.	Water %
249 ...	D	37·4	578	28
250 ...	D	37·4	623	28
251 ...	S	37·4	619	28
255 ...	S	25·5	804	27
256 ...	D	18·0	791	27
257 ...	S	18·0	786	27
258 ...	S	41·3	783	27

From time to time the clay has been taken out of the bucket for the purpose of more thoroughly puddling it, to keep its water content uniform throughout the mass. This was done after Exp. (251), and in removing the clay there was a slight indication that it was more moist towards the bottom. In spite of considerable care to get the clay thoroughly mixed ready for Exp. (252) with the autographic apparatus and 26 mm. disc, the experiment itself showed apparently a soft portion of clay about the middle of the penetration, for, the pressure of fluidity having been reached, the speed of penetration increased in the usual manner, but instead of the quick motion continuing until the disc reached the bottom of the bucket, it became slow when the disc had penetrated for about only two-thirds of the whole depth, and a considerable increase of load was necessary to cause penetration of the remaining third of the depth. In fact, the pressure of fluidity of the soft portion was only 560 grs. sq. cm., while of the clay below it was about 850 grs. sq. cm. This is a big difference, but it must be remembered that the pressure of fluidity is a delicate test of the water content, as may be seen by referring to Curve Xa at p. 58, I., connecting the pressure of fluidity and the percentage of water where it will be found that a pressure of fluidity of 560 grams sq. cm. corresponds with a water content of 29·6%, while 850 grs. sq. cm. corresponds with 27·9%, and the difference between these is only 1·7%.

In addition to the disturbing effect of the soft pocket, the clock-drum misbehaved itself badly in Exp. (252), so the experiment must be rejected, which is sad, for it took about 8 hours.

Exp. (253) was made to replace (252), but though the clock was all right, the soft pocket had not been entirely eliminated, its



AUTOGRAPHIC CURVE.

EXP: (249). 37·4 M/M. — DISC.

28% WATER.

PENETRATION IN M/M.

SET XXXI.

pressure of fluidity being 713 grs. sq. cm., while that of the clay below was about 810 grs. sq. cm. This, too, was rejected, and more man-power applied to the clay to get it uniform. Exp. (254) was started with the 25·5 mm. polished steel sphere. The guide-rod was not quite vertical at an early stage, and in trying to adjust it the clay got, for the first and only time, slightly on to the top half of the sphere. This began to make a raggy hole, and so the experiment was abandoned, and (255) was started in its stead, which was an entire success.

The agreement of the results in the last table is good, especially in the case of those when the water content was 27% for the small disc ; small, medium and large spheres all gave the pressure of fluidity with a maximum variation of only 21 grs. sq. cm., or say 2½%.

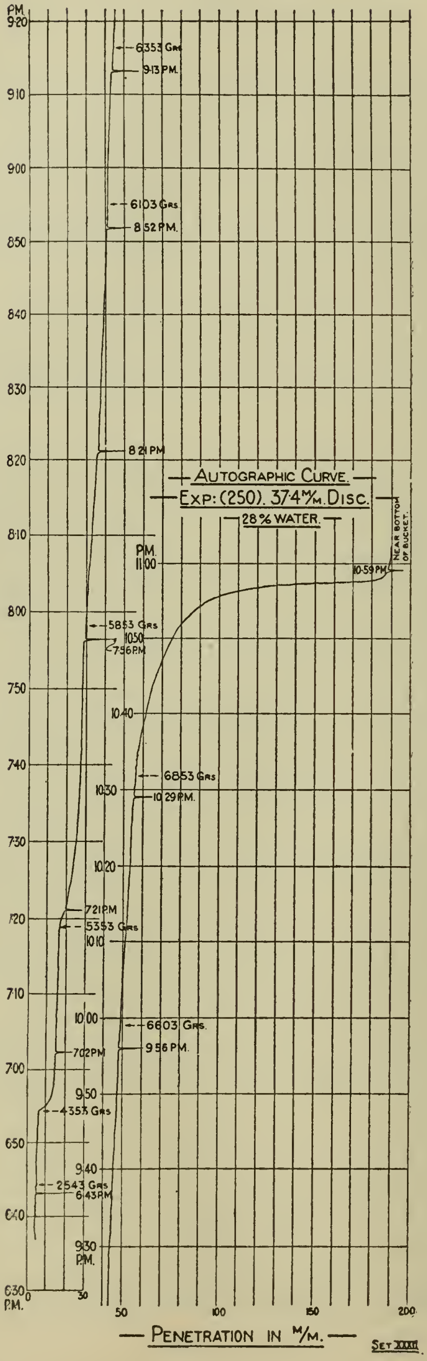
In the case of (250 and 251) the agreement is even closer. The reason for making (250) after (249) was because of some slightly unsatisfactory conditions in connection with (249).

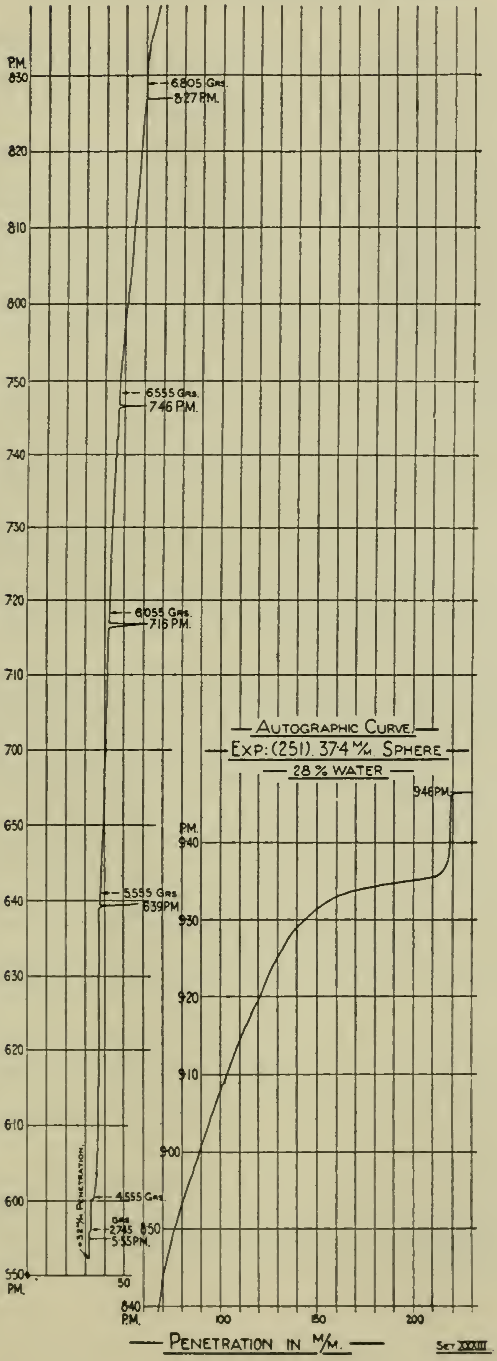
From these experiments it appears that the resistance offered to a disc or sphere of the same diameter is the same, and that the *intensity* of the resistance, *i.e.*, the pressure of fluidity, is independent of the diameter of the spheres and discs within a considerable range when fluidity has been reached.

On referring to the autographic curves for Exps. (249-251) (255-258), forming Sets XXXI. to XXXIII., each curve will be seen to bear several short lines, which are approximately at right angles to the curve, and against each such line is a time, such as 7.30 p.m. These are time marks made at the times recorded, and read on a watch as a check on the speed of the clock driving the drum. The autographic curves were drawn on plain paper on the drum, a horizontal line being drawn by the pencil to indicate zero penetration, and the time marks to give the time scale. After the paper was removed from the drum, the zero line and the time marks enabled the paper to be ruled to show 10 min. intervals of time, and centimeters of penetration.

The time marks were made by pushing the pencil carrier down a short distance, causing the silk cord attaching it to the load-guide-rod to become slack, and then back again until the cord was just taut. It will be seen that most of the time marks are in the form of long narrow V's. This was due to the general elasticity or " spring " of the recording drum and the retarding friction. The friction against rotation was relieved by the motion of the pencil at right angles to this, and hence the drum raced on the amount of the maximum width of the V.

The loading is hand-recorded on each curve, and was suitably graded according to the area of disc or sphere in use.


Autographic Curve.
Exp: (250). 37·4 m/m. Disc.
28% Water.
P.M. 9·20
9·10
9·00
8·50
8·40
8·30
8·20
8·10
8·00
7·50
7·40
7·30
7·20
7·10
7·00
6·50
6·40
6·30 P.M.
6353 Grs
9·13 P.M.
6103 Grs
8 52 P.M.
8 21 P.M.
5853 Grs
10·50
7·56 P.M.
P.M. 11·00
10·59 P.M.
Near bottom of bucket.
10·40
6853 Grs
10·30
10 29 P.M.
10·20
7·21 P.M.
5353 Grs
10·10
10·00
6603 Grs.
9 56 P.M.
7·02 P.M.
9·50
4353 Grs
9·40
2543 Grs
6·43 P.M.
9·30 P.M.
0
30
50
100
150
200
Penetration in M/M.
Set XXXII.


Autographic Curve.
Exp: (251). 37·4 M/M. Sphere
28 % Water
P.M.
830
820
810
800
750
740
730
720
710
700
650
640
630
620
610
600
550
P.M.
6805 Grs.
8·27 P.M.
6555 Grs.
7·46 P.M.
6055 Grs.
7·16 P.M.
5555 Grs.
6·39 P.M.
4555 Grs.
Grs
2745
5·55 P.M.
·32 % Penetration.
50
9·46 P.M.
P.M.
940
930
920
910
900
850
840
P.M.
100
150
200
Penetration in M/M.
Set XXXIII

The time intervals for the loading were selected by studying the autographic curve being drawn ; if this continued to show a fair amount of slope, no more load was added, but if it was nearly horizontal, then the load was increased.

In the early stages of most curves the addition of load made a marked effect on the curve, the centre of curvature of such portions of the curves being to the left of the curve. In some curves the loads about the middle of the curves caused a change of slope of the curve, but no sudden penetration, the " curve," in fact, being nearly straight, while towards the end of the experiment the increments of load caused additional curvature, the centre of curvature then being to the right of the curve.

In some cases the additional load seems to have had no marked effect.

These autographic curves bring out clearly the remarkable and sudden increase in the speed of penetration which is so characteristic of the pressure of fluidity.

In the case of Exp. (251) the 37·4 mm. sphere was forced in for the first 32 mm. by hand, this being necessary on account of an insufficiency of height in the apparatus, but in any case it was probably well to have started with the sphere in a position equivalent to that of the disc.

The autographic curve of Exp. (255) shows an apparently sudden penetration at 9·00 p.m. This was partly due to the load-rod then needing and receiving a slight adjustment to make it vertical. At 10·06 the carrier was accidently and lightly knocked in a horizontal direction, which caused the effect recorded.

At the end of Exp. (256), *i.e.*, at 1 hr. 14 min. 45 sec., the 18 mm. disc evidently dropped into a hole unwittingly left at the bottom after the previous experiment. The motion was so rapid that the momentum of the pencil-carrier carried it below the point corresponding with the position of the disc. The carrier was lifted until the cord was taut, the curve recording these facts.

In Exp. (258), at 8 hrs. 26 mins. 30 secs., the load had been removed from the load-rod (which was sometimes necessary) in preparation for increasing the load, and while unloaded the rod slipped off the sphere, and caused the " penetration " mark recorded.

Using the maximum speed of penetration as determined by means of the autographic curves, and applying Stokes's Law, we obtain the following values of the viscosity of the clay when its pressure of fluidity had been reached.

No.	Description.	Speed of penetration, v, cm. per sec.	Viscosity in millions of dyne-secs. per sq. cm.	Load in grams causing the speed v.
249 ...	37·4 mm. Disc ...	0·055	3·24	6,353
250 ...	37·4 mm. ,, ...	0·132	1·47	6,853
251 ...	37·4 mm. Sphere	0·042	4·59	6,805
255 ...	25·5 mm. ,, ...	0·006	28·10	4,112
256 ...	18 mm. Disc. ...	0·013	8·98	2,016
257 ...	18 mm. Sphere ...	0·055	2·09	2,005
258 ...	41·3 mm. ,, ...	0·148	1·66	9,716

These results, as regards the values of the viscosity, are disappointing on account of the great variation. Possibly the time scale was too small for the speed of penetration to be determined with sufficient accuracy, or the depth of clay was not sufficient to allow the speed of penetration to attain its ultimate constant value which Stokes's Law requires.

In spite of this, however, there is some interest in the individual curves, *e.g.*, that for Exp. (249) shows that the last three loads each caused a different (and increased) slope of the curve. The slope of the portion due to the 5,853 gr. load gives $v = 0{\cdot}002$ cm. per sec., and hence $\eta = 74{\cdot}9 \times 10^6$ dyne-secs. per sq. cm. The portion due to the 6,103 gr. load gives $v = 0{\cdot}006$, and $\eta = 30{\cdot}35 \times 10^6$. The 6,353 gr. load caused two different slopes ; the first gives $v = 0{\cdot}009$, and $\eta = 21{\cdot}07 \times 10^6$, while the second gives $v = 0{\cdot}055$ and $\eta = 3{\cdot}24 \times 10^6$.

In Exp. (257) the final load of 2,005 grs. caused three stages in the velocity of penetration. The middle one gives $v = 0{\cdot}017$, and $\eta = 6{\cdot}95 \times 10^6$, while the final one gives $v = 0{\cdot}055$, and $\eta = 2{\cdot}09 \times 10^6$.

CONCLUSIONS.

The conclusions arrived at as a result of the experiments herein recorded are :—

43. The pressure of fluidity was decreased about 25% as a result of boiling the clay.

44. The mean radial speed of flow of the clay from beneath the edge of a disc is about one-eighth the speed of penetration of the disc.

45. The mean speed of penetration of a disc into clay when the load is just sufficient to produce the pressure of fluidity is about 1 cm. per min.

46. When a disc penetrates clay there appears to be a stagnant " cap " of clay immediately under the disc which travels down with the disc.

47 Even under considerable tangential stress there is no progressive strain in the case of clay containing 25% of water. In other words, it then behaves as a solid and not a fluid.

48. The addition of an artificial head to the top surface of clay increases its pressure of fluidity, but even when the addition is as much as 200% of the actual head, the increase of the pressure of fluidity is only about 7%, when the clay contains 25% of water.

49. When clay is discharged under pressure through sharp-edged circular orifices, the rate of discharge increases more rapidly than the rate of increase of pressure, and ultimately there is a phenomenon analogous to the pressure of fluidity, which has been called the critical pressure of extrusion.

50. When the orifice has been plugged for a couple of hours and is then unplugged, the discharge is considerably less for some time than it was immediately before the plugging.

51. The discharge *per sq. cm. of orifice* for a given pressure is less the smaller orifice.

52. The initial pressure necessary to cause the discharge to begin increases considerably as the diameter of the orifice is decreased.

53. The greater the pressure the greater the increase of discharge *per sq. cm. of orifice* when changing from a small to a larger orifice.

54. It does not seem to matter whether a sphere or disc of the same diameter is used for determining the pressure of fluidity, *i.e.*, when the pressure of fluidity has been reached the load on the disc is the same as that on the sphere.

55. In determining the pressure of fluidity by means of a disc or sphere, the result is independent of the diameter of the disc or sphere within a considerable range.

56. That though considerable trouble has been taken to make experiments which it was thought would determine the viscosity of clay when its pressure of fluidity had been reached, the resulting values of the viscosity are so irregular that little reliance can be placed on them.

The author fully realises that many more experiments are necessary, especially of the same character (but with some differences in the conditions) as those already made, but his object has been to sketch out by means of experiments the methods of attacking the problem in the hope that other workers may be stimulated to take up the investigation.

Discussion.

Mr. T. J. Gueritte, F.S.E., Vice-Pres., said :—

We have had this evening a most interesting paper, and one which, taken together with the two previous papers on the same subject, contributed to our proceedings by the author, forms a useful starting point for further research work, while many useful results have been obtained already.

Having lately read the report (published in August, 1920), of the Committee of the American Society of Civil Engineers entrusted with the task of codifying present practice on the bearing value of soil of foundations, which touches upon some of the points covered by Mr. Ackermann's work, he was struck by the fact that the greater part of the Committee's work had been to compile information from previous sources, and that it was only quite lately that they had recourse to direct experimentation, and as far as he could see, long after Mr. Ackermann undertook his work. We were told so often that our American colleagues were more enterprising than we are, that it was refreshing to find, as regards the properties of clay at any rate, the lead was given on this side, and he thought that the Society was greatly indebted to the author for such vanguard information, as was provided for the benefit of its members.

He considered that the diagrams forming Sets XXVII. and XXVIII. were among the most interesting results set out in the paper, and they would repay careful consideration. The difference in the general aspect of the curves for clay subjected to increasing pressure, and of the corresponding ones which could be plotted in the case of water, was curious.

Again, Set XXIX. revealed an interesting case. The rapid decrease of the angle of the lines corresponding to the increase of pressure from 700 to 800, and then to 850 grammes per sq. cm. was extremely characteristic. He merely mentioned those points without going fully into them, as he believed other speakers proposed to do so at greater length. He would merely add that many remember that the problem of the flow of solid substances was first studied by Tresca, and all those who were interested in the phenomena which Mr. Ackermann had been investigating would find it useful to refer to the *Annales du Conservatoire des Arts et Métiers, T. VI., pp. 1-62, 1865 ;* further interesting developments were also presented in a striking manner in a paper read by W. Spring, of the Liège University, at the International Congress of Physics held in Paris in 1900. Although the substances then under consideration differed from that which attracted Mr. Ackermann, it was well worth while to go back to those experiments and make a parallel between a number of the points brought out then and now (See *Reports du*

Congrès Internationale de Physique T. I., pp. 402-432, Gauthiers Villars, Ed. Paris, 1900).

As regards applications to engineering practice, conclusion No. 50, to the effect that " when the orifice has been plugged for a couple of hours and is then unplugged, the discharge is considerably less for some time than it was before the plugging " deserved attention. It may be that a phenomenon somewhat analogous took place when the driving of a pile was stopped for some time and was then re-started. He had known cases of driving being stopped when the pile was going at the rate of 2 in. per blow of a 2 ton monkey dropped 4 ft. A fortnight later driving was renewed, and the first 100 blows failed to make the slightest impression on the pile. Then suddenly the pile started to move, and after a few further blows, went at the rate of nearly 2 in. per blow. The case was worth investigating further.

Conclusion No. 46, referring to the stagnant " cap " of clay under the disc, lead one to believe that further investigation should also be carried out to ascertain whether an influence of the same kind does not come into play when driving with very blunt pile shoes.

He had no doubt that a hearty vote of thanks to the author would show their deep appreciation of the value of his investigations.

Mr. William Whitaker, B.A., F.R.S., approached the subject from a geologic point of view. Geologists had generally to do with clays in bulk, as great masses ; but they were also concerned with their character, composition, and behaviour under pressure and other disturbing forces. Therefore, they were grateful for such work as Mr. Ackermann was doing.

It occurred to him that as of late years geologists had gained much knowledge concerning sands from the study of their detailed composition (especially as concerned their contained heavy minerals) which had been carried out by various competent observers ; so perhaps the study of the characters and properties of clays might in like manner add to the geologic knowledge of their common class of beds.

Nature herself had conducted experiments on the tension and pressure of clay, either by action originating from above (through infiltration of water, causing the formation of pipes in calcareous beds, and the consequent letting down of overlying clay, with considerable stretching out of the beds in many cases), or by action from below (through the puckering and folding of beds, also causing elongation or squeezing), and he hoped that the character of clays that had been thus subject to deformation might be studied.

He was always glad to see a connection between geology and other sciences, and welcomed their particular connection with engineering science. Naturally, as a geologist, he thought that one great function of engineers was to provide information for geologists, and was glad to say that engineers had done well in this matter. Of course, he hoped that, as a slight return, the engineers might be able to pick up some crumbs which fall from the geologic table.

Dr. J. W. Evans, D.Sc., F.R.S., welcomed a third paper from Mr. Ackermann, describing further experimental work on clay. Some of his results showed a striking resemblance to those obtained by the application of directed pressure to ice, especially with regard to the rate of flow through orifices. There was, however, an important distinction. In the case of ice, general and directed pressure had similar effects, both increasing the fluidity. In the case of clay, however, it would probably be found that, while directed pressure tended to produce a fluidity involving the breaking down of its structure, and therefore analogous, though not identical, with the fusion of a crystalline substance, general pressure would, on the other hand, increase the viscosity. This was shown to be the case with lubricants by Dr. H. Hyde There the rapid increase under heavy general pressure was very remarkable. It was certainly desirable to ascertain the effect of general pressure on the fluidity of clay, especially when combined with different amounts of directed pressure.

He had remarked that in the rocks of North Devon, which have been subjected to powerful earth-movements, the clays seem to have flowed, while the limestones and grits have been thrown into minor folds. In the former the pressure of fluidity was apparently reached.

Dr. W. R. Ormandy, D.Sc., remarked that the physical and chemical nature of clay varied so much from sample to sample, that the greatest care would have to be exercised in applying deductions from one sample to any other sample. To illustrate his remarks he showed two samples of china clay, each containing 50 per cent. of water, one in the presence of alkalis, and the other in the presence of a trace of acid. The acid sample was practically solid, whereas the alkaline sample was comparatively thin liquid which could be poured. Similar samples of ball clay were shown to demonstrate that this peculiar action of traces of electrolytes applied to two varieties of clay as far apart physically as the meagre non-plastic china clay, and the fat or strong plastic ball clay.

He thought it was a great pity that Mr. Ackermann had not carried out his experiments with pure clay substance such as china clay or ball clay, or preferably with both, as although these two products had almost identically the same chemical composition they formed two extremes in the clay family as regards their physical properties. With reference to Mr. Ackermann's discovery of the results obtained with a clay which had stood for some time, or which had been spoiled, compared with the behaviour of a newly mixed clay, he pointed out that this was a well-known experience in the pottery industry, and that it was well-known that clay masses became more plastic if allowed to stand, and that, indeed, the Japanese and Chinese potters generally used clay for potting purposes which had been mixed by their forefathers.

He was of opinion that the increased pressure of fluidity obtained when the top surface of the clay was loaded was about what one would have expected on the assumption that the clay and water was an incompressible material, and that the whole experimental arrangement acted like an hydraulic press. He concluded by expressing his interest in Mr. Ackermann's work, particularly in the proof that it offered that valuable research could still be done in some directions without the expenditure of large sums of money on intricate or delicate plant.

The Chairman mentioned that **Mr. P. J. Neate, M.I.Mech.E.,** who was present, had studied the flow of cement and brick earth slurries, and asked him to contribute some information concerning a brick earth pumping plant and 4¼ mile pipe line near Berlin.

In response, Mr. Neate stated that the brick earth plant in question was designed and constructed by him to supercede tramming. The brick earth contained a good deal of sand and much of this after washing had to be settled out before pumping. The specific gravity of the pumped slurry was 1·35. About 14 cubic metres of earth were thrown into the wash mill per hour, and 1 metre of sand trapped off, leaving 13 cubic metres to be pumped through the 5 in. diam. cast iron pipe at a pressure of 145 lb. per sq. in. The pumps consisted of 3 plungers 7 in. diam. by 16 in. stroke, and ran about 20 revolutions per minute. A large quantity of sand passed through the pipe and was settled out close to the river side and sold to builders.

Owing to lack of slurry the pumps often stopped, and then sand settled in the pipes and had to be washed through with clean water for an hour each night.

Mr. Neate also gave the results of two other similar cases in which the pipe was 6 in. diam. and 850 ft. long, and the material thick and thin cement slurry—chalk mixed with clay. The salient features of this diagram were that even this slurry

(40 per cent. water) behaved like a solid and refused to move till a pressure of about 35 lb. per sq. in. on a length of 850 ft. of 6 in. cast iron pipes was reached. When once started, the pressure rose almost exactly in proportion to the velocity up to 60 lb. per sq. in., for a velocity of 2·7 ft. per second.

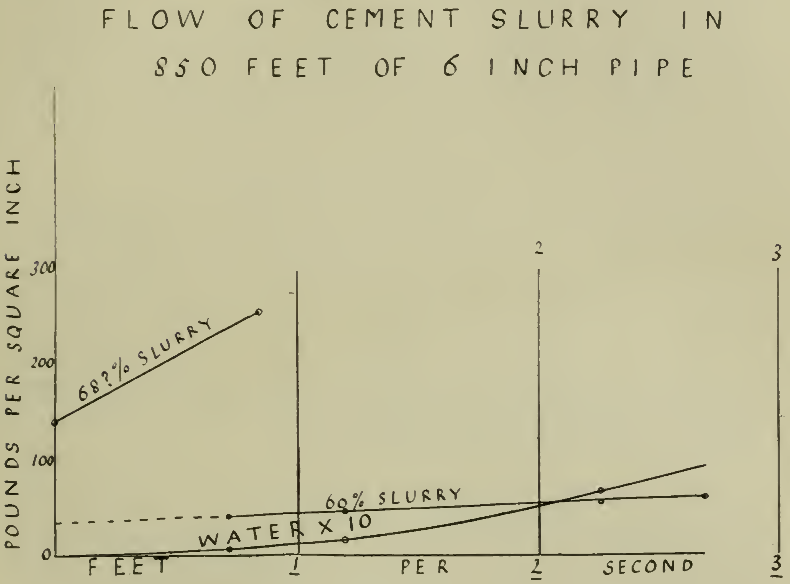


FIG. 1.

With thicker slurry—about 32 per cent. water—the same sort of results were obtained at very much higher pressures.

He pointed out that these results fully corroborated Mr. Ackermann's work, and commented from personal inspection on the very beautiful adaptation of unpromising looking apparatus to truly scientific uses and accurate results, which the author had improvised during his research.

Mr. Neate was unable to show at the meeting, but has since contributed a sketch of a diagram (Fig. 2) drawn by him with a horizontally moving pencil on a sheet of paper attached to a pile (and, therefore, moving vertically with the pile) as a blow was struck. This pile was being driven into clay, and the diagram showed a rebound of nearly half the initial penetration, due for the most part to the elasticity and rebound of the clay in which the pile was embedded.

Mr. Neate would also like to add that in his experience pure chalk slurry with a given percentage of water varies in

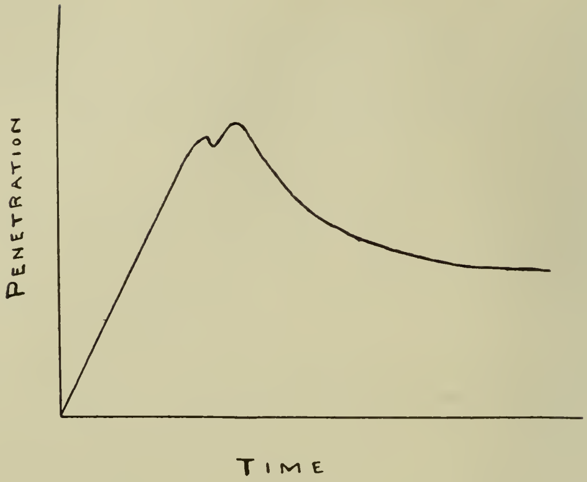


Fig. 2.

consistency much as ball and china clay vary, hard semi-crystalline Yorkshire chalk needing much less water than soft Kentish chalk to produce the same consistency.

Mr. F. Bolton, M.Inst.C.E., M.I.E.E., said the author's third paper on his researches into the properties of clay continued to be of the greatest interest. He felt that the greatest results of his investigations are his various experiments proving the fluidity of clay under differential pressure, and that no labour can be wasted in establishing this to be a fact or not. Contrary to others, he did not feel that the author's time would be well spent in conducting experiments on various types and mixtures of clays and sands, but rather that these should be carried out by students after a proper routine had been worked out. He suggested that such a series of experiments might be scheduled by the author, and left for some institution or college to complete.

Doubt had been cast on fluidity being always a property of clay, and criticism had been levelled at the author's "fluidity" experiments being conducted with a too rapid loading. With the autograph apparatus described at pp. 108-112 there should be no difficulty in extending typical experiments over long periods, as load could be applied very slowly, say, by means of water or shot. It had been suggested that the kinetic energy of the load might have some misleading effect. By working out the increased pressure due to kinetic energy, assuming it were absorbed whilst penetrating one-tenth of a millimetre, the increased pressure on account of the movement would be only about one-tenth of 1 per cent.

Assuming that clay acted as a fluid under a sufficient differential pressure, it was of interest to apply hydraulic conceptions to the results of the experiments to see the results.

The curves, Set XXVII., give the results of extrusion experiments, and Mr. Bolton submitted that fluidity commenced when extrusion began, not when an increase of differential pressure produced a largely increased quantity extruded. Taking this as a basis, and neglecting the abnormal results of the 15·1 mm. orifice, which were apparently due to the clay setting or to some reason unaccounted for, the following results were obtained :—

Diameter of orifice in mm.	Differential pressure of fluidity. grams per sq. cm.	Hydraulic mean radius in mm.	Product.	Difference from mean of product A × B.
	A.	B.	A × B.	
20·2	240	5·05	1,212	– 4%
12·4	365	3·1	1,131	– 10%
10·1	550	2·525	1,389	+10%
7·5	660	1·375	1,237	– 2%
5·0	1,060	1·25	1,325	+ 5%
		mean	1,259	

The results were not as constant as might have been anticipated, but allowing for variations in temperature, percentage and quality of water, it would appear that they might be actually more in line than they seemed to be. To overcome these variations it was suggested that an orifice plate be made containing various sized orifices. On increasing pressure being applied, clay will be extruded from the largest orifice first. On this orifice being plugged and the pressure increased, clay would be extruded from the next largest orifice, and so on. Useful deductions might be made by noting at what pressures extrusions commenced through the various sized orifices.

Mr. A. Stewart Buckle, M.Inst.C.E., said that he would like to open up a question with regard to clay which, if fully discussed, would probably occupy a good deal of time. It was, Why did the Israelites require straw for making bricks ? The popular idea, as illustrated by the proverb, was that you cannot make bricks without straw. The fact was, however, that we not only could make bricks without straw, but we were puzzled to know why the Egyptians needed it.

Some years ago, when he was in India on railway construction, and had to make a great many bricks for the bridges, he received a circular issued by the Government of India on this subject. It appeared that an American had gone into this question and had come to the conclusion that the straw was boiled in order to get the tannin out of it, and that by mixing the tannin with the clay it was thereby made more plastic.

The circular of the Government of India quoted from the Bible the portion, which runs as follows :—

" And Pharoah commanded the taskmasters of the people and their officers saying : ' Ye shall no more give the people straw to make bricks as heretofore : let them go and gather straw for themselves.' . . . So the people were scattered abroad throughout all the land of Egypt to gather stubble instead of straw."

The use of the word " stubble " certainly lends colour to the assumption that the straw was not used as a binding material. Recipients of the circular were asked to make experiments accordingly, but he regretted that no useful result was obtained from the experiments made.

Mr. P. J. H. Unna, A.M.I.C.E., remarked that the trumpet-shaped hole that was found to form in the body of the clay in the " container " used for the extrusion experiments was similar to the holes that appeared in the bed of a river on the outside of a dam when a blow was experienced during the excavation of the ground inside. An instance of this occurred about the year 1900, when the new entrance to the Greenland Dock of the Surrey Commercial Docks was being built. The strata was exactly similar to those already mentioned by Mr. Whitaker—clay over Thanet sand over chalk. A serious blow occurred at a point about 100 yards within the dam (the piles of which penetrated into, but not through, the clay) when the excavation had been taken almost down to the top of the sand. At the same time several sink holes were formed in the bed of the Thames at a short distance outside the dam. These holes presumably had a direct connection with the blow by way of the stratum of sand. Their exact shape was not ascertainable, but when, at a later date, a wharf had to be built on their site, the piles used in constructing it sank down to the sand with practically no driving. This indicates that when the supporting sand was withdrawn, the clay did not merely bend or flow under its own weight and that of the superimposed water in order to fill up the cavity, but that definite holes were formed in the stratum of clay, which was of considerable thickness, in a similar manner to the ones that formed in Mr. Ackermann's experiments.

Mr. P. M. Crosthwaite, M.Inst.C.E., wrote saying he had read the author's third paper with interest, and desired to place on record the admiration he felt for his perseverance in continuing such laborious experiments. In discussing Mr. Ackermann's second paper he had drawn attention to the effect of loading the disc at equal, short intervals of time instead of waiting in each case for the disc to come to rest before applying another load, as in similar experiments made by him (Mr. Crosthwaite). The point at which what Mr. Ackermann called the "pressure of fluidity" occurred varied enormously with the rate of loading. For instance, in one experiment with 7 lb. loads applied at intervals of 10 minutes, "fluidity point" was reached with a pressure of 7·75 tons per sq. ft., the experiment taking 2½ hours, while the same clay carried loads of from 12·9 to 19·8 tons per sq. ft. without any sign of "fluidity" having been reached, when time was allowed for the disc to come to rest before additional loads were added, the latter experiments taking from 13 to 58 hours each. The reason assigned for these different results was that with fast loading the clay was subjected to a "live" load, but that when the plunger was allowed to come to rest each time the load was practically "dead." In Fig. 3 penetration curves are shown for clay (*b*) when loaded at equal intervals of time, and (*a*) when the disc was allowed to come to rest before adding additional load. In this connection he drew attention to two most instructive papers, the first by Adams and Bancroft, and the second by King, published in the "Journal of Geology," Vol. XXV., No. 7, Nov., 1917, "On the Internal Friction in Rocks during Deformation." The rocks in question were enclosed in nickel steel cylinders, the rocks being compressed longitudinally, and the conjugate pressure measured from the bulging of the steel cylinders. The force required to deform the cylinders was determined by deforming them with oil, water and tallow inside instead of rock.

After allowance was made for the stress absorbed by the steel cylinder, a number of curves were plotted, showing the resistance of the rocks to lateral deformation. At p. 633 of the first paper two diagrams were given showing the effects of rapid loading, the results being exactly the same as those obtained by Mr. Crosthwaite, though, naturally, the deformations obtained from solid rocks were minute. In one experiment 36,000 lb. was applied in equal increments of 1,000 lb. each, and allowed to remain till no movement was observed for two minutes. The next 1,000 lb. was by mistake put on suddenly, and the deformation produced by it was three-quarters as great as the total deformation due to the preceding 36,000 lb. The authors attributed this to "submitting the rock to an impact instead of a slow increase of pressure." Had the authors finished their experiment at this point it

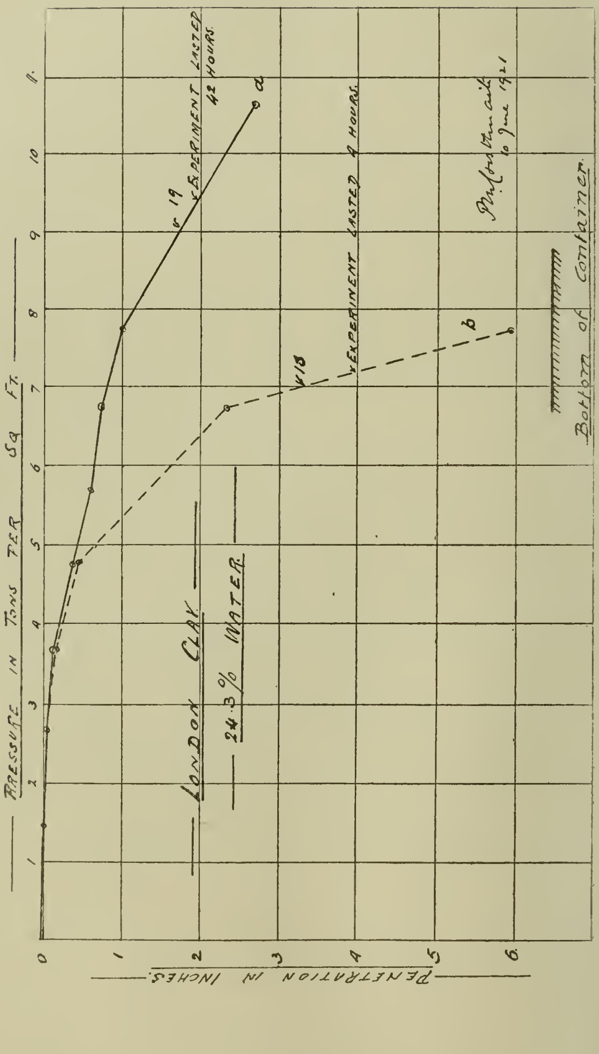

PRESSURE IN TONS PER SQ FT.
0
1
2
3
4
5
6
7
8
9
10
11
PENETRATION IN INCHES.
0
1
2
3
4
5
6
LONDON CLAY
24.3% WATER
EXPERIMENT LASTED 42 HOURS.
EXPERIMENT LASTED 4 HOURS.
19
18
a
b
10 June 1921
Bottom of Container.

FIG. 3.

might have been concluded that they had reached a point of fluidity. The experiment was, however, continued. Four additional loads were added without any further deformation, the next two loads produced slight deformation, and then the original curve was resumed. Had this experiment been made in an open bucket of clay the plunger would have reached the bottom, but here the steel surrounding cylinder prevented the indefinite penetration of the plunger. Some of the curves shown by the authors bear a striking resemblance to those obtained by Mr. Crosthwaite for stiff clay.

In his first experiment, made in 1915 and described in his paper in the Proc. Inst. C.E., Vol. CCIII., Part I., it was found that the penetration of a loaded cylindrical plunger varied as the square of the load. In these experiments, however, the highest pressures reached were about 5 tons per sq. ft. In his later experiments, with a loaded disc, pressures up to 20 tons per sq. ft. were imposed on the clay, and for these higher pressures the square law did not hold, the penetrations being considerably greater than this could give.

Returning to the rock experiments, they showed conclusively that the rocks could sustain greater pressures for equal deformations as the thickness of the containing cylinder increased, and from this the authors conclude that the greater their depth the greater was their resistance to deformation. If this conclusion were justified it was evident there can be no definite " pressure of fluidity," for them, but that they will begin to flow at a pressure dependent on their depth below the surface. This was what Mr. Crosthwaite had originally suggested in connection with clay. When considering these disc experiments, it must be remembered that when the disc was coming to rest it was approaching exact equilibrium, and its movement was extremely slow. Slow as it was, however, there must be a great difference between an additional weight added to a considerably larger weight that was already in motion than if it had been added when the latter was at rest.

The view Mr. Crosthwaite held was that before the pressure of fluidity could be accepted, experiments would have to be made on a scale that would allow a penetration of many feet, and no additional loads must be added till it was certain the disc had come to rest. Also, the load must be added in small increments, and the disc prevented from acquiring an acceleration. It was, no doubt, unfortunate that clay continued moving in such a deliberate fashion when loaded, but there it was, so we must make the best of it.

Mr. James Mitchell, M.Inst.C.E., remarked that Clerk Maxwell in distinguishing between solids and fluids, said : " When a continuous alteration of form is produced only by a stress exceeding a certain value, the substance is called a solid, however soft and plastic it may be. But when the smallest stress, if only continued long enough, will cause a perceptible and increasing change of form, the substance must be regarded as a viscous fluid, however hard it may be." He instanced a jelly as a soft solid, and a block of pitch as a hard liquid.

The author, in speaking of the "pressure of fluidity" in the clay directly under a pile, appeared to have in his mind a condition of the clay in that locality, such that it would exhibit one of the characteristic properties of a liquid, viz., that any body having a greater specific gravity than itself would sink through it to an indefinite extent, given a sufficiency of time. Were this so, then the clay at this place would exert a lateral pressure exactly equal to the vertical pressure exerted on it. There is nothing, however, in any of the experiments described which gives the slightest support to such a view.

Referring to the remarks on viscosity at page 103 of the paper. while it was probable that a sphere of a material having a specific gravity, say, enormously greater than that of lead, would gradually sink through clay, and that after a certain depth had been reached the clay might close in behind the sphere, it was certain that a sphere of a material whose specific gravity was only slightly greater than that of the clay would not sink. This definitely separated clay from the class of viscous fluids.

Clays must be regarded as plastic solids, varying in constitution, and having characteristics affected largely by the proportion of moisture they contained. One of the great problems affecting the work of the engineer was : Given a certain vertical pressure on a given mass of clay, what horizontal pressure would be exerted by the clay at a given depth, either immediately or after a lapse of time. In spite of a considerable amount of experimentation and a very great deal of discussion the subject was still far from being clearly understood.

While this was so, the author deserved credit for the great amount of time and trouble he had devoted to the elucidation of what was a very complex and difficult problem.

Dr. Hele Shaw, LL.D., F.R.S., M.I.C.E., M.I.M.E., M.I.E.E., wrote, saying :—

The observations and records in the third paper by Mr. Ackermann on the "Physical Properties of Clay" reveal a number of most interesting facts, the chief amongst them being the valuable data concerning the flow of clay through orifices. The diagrams and curves at pp. 100-102 leave no doubt whatever not only of the difference between the flow of clay (which is a plastic solid) and the flow of a liquid, but also seem to prove that the curves at any rate of the flow of water through an orifice are reversed, the parabolic axes of the relation between discharges and pressure in the two cases being inverted.

The author points to the fact that when the pressure of fluidity is reached it acts as a viscous fluid, and it is possible to discover its viscosity. The viscosity of clay certainly cannot be determined in the same way as the viscosity of liquids is measured, and the careful and ingenious attempts to determine the viscosity of clay have enabled him to arrive at results of great interest. At p. 104 results are given for clay containing 29% of water, and what makes the work of this paper the more valuable is that the results, which are hard to understand, are faithfully recorded.

It is only by means of researches such as those upon which Mr. Ackermann has been so long and patiently engaged that many undetermined and obscure physical properties of clay can really be arrived at, and the laws regulating its movement and pressure can be determined. There is no doubt that the older assumptions upon which the engineer had to rely for his data in putting down the foundations of structures were very unsatisfactory, but from the data already available from Mr. Ackermann's experiments, and the work he is proposing to carry on in future, the civil engineer will ultimately have a much more definite basis for such all-important matters as the foundations of buildings and far-reaching questions as embankments, dock walls, and other structures in clay soil.

THE AUTHOR'S REPLY TO THE DISCUSSION.

Mr. Ackermann, in reply, thanked Mr. William Whitaker for his continued assistance and sympathetic encouragement in the work.

Dr. John Evans considered it was desirable to ascertain the effect of general pressure on the fluidity of clay. This had been done, and was referred to in the author's reply to the discussion on his first paper, read before the Society on March 10th, 1919, p. 102. The experiments, as far as they went, showed no effect of a general pressure, not even when a filament of clay only 2 mm. in diameter and containing 32% of water was subjected to a general pressure of 1,410 grs. per sq. cm. The experiments recorded in the present paper, in which an artificial head was applied to the clay, showed that the pressure of fluidity was slightly raised thereby.

Dr. Ormandy's exhibits of two samples of china clay, each containing 50% of water, but in very different states as regards resistance to deformation, were most interesting, and showed the importance of the presence of small quantities of acid or alkali. The effect of a small change in the percentage of water was, however, hardly less remarkable; e.g., when the water content of the clay was reduced from 25½% to 22% the pressure of fluidity increased nearly fourfold, namely, from 2,000 grs. sq. cm. to 7,400 grs. sq. cm.

Dr. Ormandy recommended that the experiments should be conducted with pure clay substance, such as china clay or ball clay. There was much to be said for this, especially had the experiments been started with such a material, but having begun with the particular sample of London clay, the author considered that it would be unwise to change until the present set of experiments had been completed, as otherwise the later results would not be comparable with the earlier ones.

Mr. Neate's experience with the pumping of cement slurry was particularly interesting from the fact that though in one sense so different from the discharge of a much stiffer clay through sharp-edged circular orifices, nevertheless it appeared to confirm the author's work on such discharge. Another way of putting Mr. Neate's experience was that in order to get twice the amount of slurry through the 4¼ mile 5 in. cast iron pipe that he used, it would have been necessary (had the slurry obeyed the same laws as water) to increase the pressure head fourfold, whereas, in fact, Mr. Neate found that the discharge was doubled when the pressure was only a little more than doubled. The curves at p. 100 indicated the same phenomenon, namely, that in order to get double the discharge of clay through a particular orifice it was not necessary to quadruple the pressure, which was the case with water ; e.g., if the 10 mm. orifice were considered, it would be seen that for a pressure of 780 grs. per sq. cm. the discharge was 5 grs. per minute, while when the pressure was increased to only 825 grs. the discharge was 10 grs. per minute. The phenomenon was the converse of that in connection with the propulsion of ships, where to obtain the last knot the expenditure of coal had to be increased greatly, while in the case of discharge of clay through an orifice, the last small increase of pressure produced greatly more effect than the same increase at a lower pressure.

Mr. Neate's semi-autographic diagram of the movement of a pile during, and for a fraction of a second after, the blow of the monkey, was instructive. The author was unable to see, however, how the elasticity of the pile itself could be separated from that of the clay without further experiments.

Mr. Bolton had suggested a variation of the extrusion experiments by having an orifice plate containing not one orifice, but a number of different diameters, and plugging those not in use. Such an arrangement would certainly ensure that the clay was in identically the same condition for each orifice, but it would materially add to the expense of the experiments, as the container would have to be of a much greater size, for it would be necessary to have the orifices spaced at considerable distances from one another in order to be sure that there was no effect on the clay due to the discharge from the surrounding ones. The experiments made showed that an irregular and vertical hole formed in the clay over the orifice, and it would obviously not do to have such a hole near the clay which would ultimately be extruded through an adjoining orifice. The author did not think there was much objection to the methods which he had adopted for making a set of extrusion experiments in one day with clay which had been thoroughly puddled to get it uniform at the start, the only change in each experiment being in the diameter of the orifice.

Mr. Crosthwaite referred to the effect of the time intervals, at which the increments of load were added, in the case of the experiments with discs for the determination of the pressure of fluidity. This effect was recorded by the autographic curves connecting time, penetration, and load given in Sets XXXI to XXXIII. Some other autographic curves, not published, had shown the same effect, namely, that the penetration did continue very slowly for a long time without an increase of load, after a certain stress had been attained, but the term "pressure of fluidity" had been applied to the particular phenomenon which occurred *when the increments of load were put on at equal intervals of time*, and what happened when the loading was not so done was another matter. The two curves forming Fig. 3 and supplied by Mr. Crosthwaite, excellently brought out the difference due to time intervals of loading. The author suggested that the cause of the difference was that in the case of the experiment, which lasted 42 hours, the clay had had time to set, and then needed a much larger stress to start it moving again. This phenomenon had been recorded by the author at p. 97-8 hereof in connection with the extrusion experiments. Possibly it was also connected with the difference between the static and dynamic friction of the molecules of clay against one another. Col. Lordly, at Cornell University, used a container which was 3 ft. deep instead of only 1 ft. deep, such as Mr. Crosthwaite and the author had used, and Lordly found that the disc (apparently when loaded at regular intervals) did proceed right to the bottom of the 3 ft. container, after the pressure of fluidity had been reached. Mr. Crosthwaite had, in his discussion of the author's second paper, confirmed the phenomenon of the pressure of fluidity, as defined (vide pp. 238 and 239 of that paper), and he had also confirmed it in an occult manner in his discussion of the present paper, for in paragraph 3 of his remarks he pointed out that in his later experiments the penetrations were considerably greater than proportional to the square of the load. This was only another way of saying that the curve connecting load as ordinates and penetration as abscissæ became more nearly horizontal as the pressure increased. This was exactly what the author's curves exhibiting the pressure of fluidity showed. See, for example, set XI., at p. 57 of the first paper.

Mr. James Mitchell considered that, in connection with the pressure of fluidity, the author had in his mind a condition of the clay under the disc such that it would exhibit one of the characteristic properties of a liquid, namely, that any body having a greater specific gravity than itself would sink through it to an indefinite extent. The author admits that for a short while before the first paper was published he held that idea, but by the time the first paper was published he had entirely dispelled it by experiment and reasoning. The experiment and reasoning were both recorded in the author's reply to the discussion of his first paper at p. 102 therein. Briefly, a general pressure on a whole mass of clay did *not* render it fluid. The phenomenon of the pressure of fluidity was only exhibited where there was a differential pressure, *i.e.*, when one portion of the clay, namely, that under the disc, was much more heavily loaded than the adjoining clay, the load on which was due to the head of clay above it, and probably what might be called the " net pressure of fluidity " was the stress which was necessary to cause the apparently indefinite penetration of the disc, *minus* the pressure in the immediately adjoining clay due to the statical head. In the experiments so far made, especially with the drier clays, the pressure of fluidity was many times the stress due to the statical head, so that the correction due to deducting the latter was a small percentage one. Mr. Mitchell was of opinion that the experiments did not give the slightest support to the view that when the pressure of fluidity was reached the lateral and vertical pressures were equal. The author admitted he had not *proved* this, but contended that several of his experiments indicated it, and Mr. A. L. Bell *had proved it : vide Proc. Inst.C.E.*, Vol. CXCIX., p. 240.

The author's experiments with loaded spheres seemed to him to be exactly equivalent to a sphere " having a specific gravity enormously greater than that of lead," as suggested by Mr. Mitchell.

Mr. Mitchell said that one of the great problems affecting the work of an engineer was " given a certain vertical pressure on a given mass of clay, what horizontal pressure would be exerted by the clay at a given depth ? " This was the problem the author originally set out to determine by means of the experiments with the square pyramids. The experiments failed as at first designed, though they led to many other interesting results, as recorded in the first paper, and it was only after separate experiments were made to determine the co-efficient of friction that he was able to utilise them for the purpose of finding the horizontal reaction of the clay. This work is recorded at pp. 204 and 205 of the second paper and the relationship of the horizontal reaction to the vertical pressure is there given.

VISIT TO THE INCHINNAN AERODROME TO VIEW THE AIRSHIP R. 36

(Constructed by Messrs. Sir William Beardmore & Co., Ltd.)

on the 18th March, 1921.

By W. R. Taylor, A.M.I.Mech.E., A.M.S.E.
(*the Society's Representative on that occasion*).

By the courtesy of the constructors, motor charabancs met the trains at Paisley Station and conveyed visitors to the aerodrome. On entering the shed the first impression is amazement at the huge size of this fine airship. It practically fills the shed in which it has been built from end to end and from floor to roof. The services of the engineering staff were kindly placed at the disposal of visitors, and in this way some very useful information was obtainable.

R. 36 was designed by the Admiralty more than three years ago for naval purposes, and, although she does not embody the marked improvements in design which have been elaborated during the past year, she is a very fine ship notwithstanding.

The principal dimensions are as follows :—

Maximum diameter, 78 ft. 9 in.
Height, 91 ft. 7 in.
Gas capacity slightly over 2,100,000 cu. ft.
Nominal lifting power, 63·8 tons.
Maximum speed, 65 miles per hour.
Normal cruising speed, 50 miles per hour.
Number of engines, 5.
Engine horse power, 1,570.
Lift available for fuel, freight, passengers, etc., 30 tons approximately.
Petrol and oil consumption per 100 miles' journey (normal), 0·65 ton.

The gas-containing hull consists of a skeleton streamline framework built of duralumin girders of lattice type rivetted together. This framework is divided into chambers, in which are situated the nineteen drum-shaped gas bags, and is covered with sheets of cotton fabric tightly stretched and doped. Each gas bag has an automatic gas release valve, and some are also fitted with a hand-controlled valve to enable the gas to be discharged while landing, or to alter the trim of the ship. Immediately below the gas bags are the quarters for the crew. This accommodation is in the keel of the vessel and is furnished with mess table and all necessary conveniences, the hammocks being slung between the girders.

An entirely new departure in British airship construction is the provision of a passenger car, or saloon. Accommodation is provided for fifty passengers, the saloon being over 130 ft. long. Situated about the centre of the saloon is the kitchen. The kitchen arrangements are to be of the most up-to-date description, but were not completed at the date of the visit. The saloon has a central gangway floored with 3-ply wood carried on the frame girders. On each side of the central gangway are the passengers' cabins. Each cabin has accommodation for two passengers, and is furnished with two beds, two wicker chairs and a light table. During the day time the beds are folded up out of the way (a very ingenious arrangement), while at night the table folds back against the side of the ship and brings into use a large mirror fixed to the underside of the table top. All necessary lavatory accommodation is provided amidships, the water supply being from the tanks above.

The power is provided by five engines housed in separate cars. They comprise three "Sunbeam-Cossack" engines of 350 H.P. each, and two "Maybach" (German) of 260 H.P. each. The cars are arranged two forward, two amidships, and one aft.

The "Sunbeam" engines have twelve inclined cylinders each, and are of the standard type airship engine manufactured by this well-known firm. The two "Maybach" engines have eight vertical cylinders set in line. A very ingenious and interesting feature is the starting gear. By raising a lever all the valves (inlet and outlet) are raised from their seats, and a valve situated in the exhaust manifold is closed. Petrol mixture is then drawn into all the cylinders by a hand operated suction pump; the valves are closed again and the engine is started by the "starting" magneto. It will, of course, be understood that the engine is set ready for firing on one of the cylinders before the mixture is drawn in.

The "Sunbeam" engines are all fitted with reduction gear boxes, those in the amidship cars being reversible. The propellers are two-bladed and measure 18 ft. from tip to tip. The petrol supply is stored in sixty-five tanks, each containing 92 gallons, situated in the keel of the vessel.

The control car is at the forward-end of the saloon, and is equipped with all the necessary instruments for communicating with the various parts of the ship, and also with the latest navigating and recording instruments and chart table. At the after end of the control car is the wireless telegraphy and telephony outfit. This installation is of the most modern type, and, besides long range instruments, includes directional finding apparatus.

R. 36 is fitted with stabilising fins of ample area and large rudders and elevators. The rudders and elevators are operated from the main control car. Auxiliary steering and elevating gears are fitted in the after end of the ship. The arrangements for handling and mooring the ship on the ground and in and out of the sheds are of the most approved type, and the ship is fitted with all the necessary equipment for connecting to a mooring mast.

The convenience and safety of being able to moor a ship of this description to a mast in place of taking her in and out of a shed every time is undoubted. The advantages include greater safety in mooring, elimination of delays hitherto frequently occurring when handling by men, greater convenience for passengers embarking and disembarking, and increased facilities for re-fuelling and re-gassing.

Crew.—A normal crew of 4 officers and 24 men is carried. The officers consist of :—

The Captain,
1st Officer, pilot,
2nd Officer, pilot.
Engineer Officer.

The crew consists of :—

2 Coxswains,
7 Riggers,
13 Mechanics,
2 Wireless Operators.

In large ships, such as R. 36, the crew is divided into watches, which take alternate spells of duty and rest, as is the old established custom of the sea. The only exception to this is the captain, who is not necessarily continuously on duty. Thus, when the flying is difficult he remains on duty in the same way as a steamship captain remains on the bridge when approaching the coast or in bad weather, and when the flying is straightforward he goes off watch. The remaining members of the crew usually keep watch for four hours on and four hours off. The 1st and 2nd officers of the airship take command under the captain in alternate periods of watch-keeping as on board H.M. ships. The riggers correspond to the seamen in the Navy, the 1st and 2nd coxswains being the two senior riggers. The group of riggers is divided into two watches, one under each coxswain, and their duties during flight usually comprise height control, steering (lateral control), and watch-keeping in the keel.

In their periods off watch the crew take their meals, etc., in the quarters in the keel, which are furnished with mess tables and all necessary conveniences, including a gramophone. Hammocks are slung between the girders along the keel.

The petrol storage arrangement will enable the ship to fly 4,000 miles without refilling, and allowing an ample margin of spare fuel in case adverse winds are encountered. It is reasonable to expect the ship to accomplish the following journeys:—

(1) *To Stockholm* ... 30 passengers and 2 tons of mails or goods or *extra* passenger baggage in 20/24 hours.
(2) *To Switzerland* ... 40 passengers and 2 tons of mails or goods or *extra* passenger baggage in 12/15 hours.
(3) *To Marseilles* ... 30 passengers and 2 tons of mails or goods or *extra* passenger baggage in 15/18 hours.
(4) *To Egypt* ... 30 passengers and 1 to 2 tons of mails or *extra* passenger baggage in about 72 hours.

In addition to the weight of a passenger and his clothes, an additional allowance of 100 lb. per passenger has been made for hand luggage.

On each of the above routes a considerable saving of time is effected compared to other forms of transport—particularly in the case of Egypt. At the same time it should be remembered that the main function of the airship is long-distance transport, and the saving on a typical airship route of the future will be very marked, *e.g.*, England to India, where the airship voyage would occupy approximately six days, as compared with the fastest overland and mail route of twenty-one days.

COHESION:

GENERAL REVIEW OF HYPOTHESES AS TO MOLECULAR FORCE.

By Herbert Chatley, D.Sc.(Engineering) Lond., Fellow of the Physical Society.

There are numerous hypotheses as to the nature and laws of molecular force, and the object of this note is to summarise the general position and show the tendency in favour of an electrochemical hypotheses.

The principal hypotheses are the following:—

(1) Gravitation—(Kelvin);
(2) Kinetic—(Tolver Preston);
(3) Unique—(Bayma);
(4) Electrochemical—
  (*a*) Major Valencies (Nernst & Schonflies);
  (*b*) Partial Valencies (Thiele, Veles, Svedberg, Langemuir, Abegg);
  (*c*) Residual Field (Sutherland)—
    1. Multipolar systems;
    2. Alternate point systems;
(5) Electromagnetic (Crehore, etc.);
(6) Enhanced gravitation (Maxwell);
(7) The granule and similar sub-atomic theories (Reynolds, Lodge, etc.).

These theories are all interrelated to various hypotheses as to atomic and molecular constitution.

Without going much into that question, it may be mentioned that the various following fundamental assumptions have been made:—

(*a*) Immaterial points with repulsion from the central point to a certain limit, beyond which there is attraction (Boscovich).

(*b*) Essentially attractive and repulsive elements in concentric shell structures statically balanced but oscillating (Bayma).

(*c*) Mutually attractive cores surrounded by ether envelopes, which are attracted to the cores, but mutually repulsive (Pictet, Redtenbacher).

(*d*) Quasi planetary systems with positively electrified nucleus or sphere of influence and numerous negative electrons in shells or rings, the outer units of which may be unstable (Thomson, Rutherford, Bohr, etc.). These electron structures are variously regarded as static or kinetic, or a combination of both. There are certainly some kinetic features, and Thomson has recently shown that static stability requires an additional force not varying as the inverse square, and (or) that the force between electrons may follow a more complex (periodic) law at minute distances. Kinetic equilibrium, including perturbations, discrete changes of energy and uncertain central forces, is still more indeterminate.

A paradoxical position arises by postulating ideal simple point charges as the units of the atomic structure, since it appears that they may not follow the rules of Newtonian mechanics, and the ether drags at the probable speeds modify the fundamental concept of mass. In other words *the simple concept of an electron as a structural unit of substance is not reconcilable with the simple concept of constancy of mass.*

Molecules are agreed to be atomic structures and investigations on crystals indicate that true molecules acting as whole units only exist in fluids, being interlocked in solid crystals in such a way that molecules have no individuality except as arbitrary but stable groups of structural atoms.

If, now, the electrostatic and electromagnetic forces in such atom structures or between free molecules are known, the differential, *i.e.*, electrical and magnetic attractions, minus similar repulsion effects, *may* explain cohesive attractions. Vice versa, if the law of space variation (linear and angular) of the latter is known, confirmation or otherwise of the atomic structure and polarisation will be found.

Analysis along these lines indicates two alternative types of regular structure which may be realised in crystals :—

(*a*) A lattice of atoms, each acting as a point charge located at its centre, attracting dissimilarly charged atoms and repelling similarly charged atoms.

(*b*) A lattice of multipolar atoms (at least doublets of two charges), with free charges at or near the periphery and geometrical centres respectively.

Strong arguments of a quasi-metaphysical character have often been urged in favour of the inverse square law for cohesion (particularly in the score of simplicity). Such a law can only be applicable to cohesion if the resultant forces are differential.

Nevertheless, so great a physicist as Kelvin held a purely Newtonian view of cohesion, considering that the molecules attracted very strongly at close proximity owing to their density. He does not seem to have made any computations, but apparently the idea is that great density (*i.e.*, minute volumes) would permit close approximation, but there is a paradox in this that the general density would also be increased.

In order that two molecules shall cohere, with forces actually known to exist in minute drops (when the effect of total mass is small) say, even as little as 10^{-10} dynes, the distance between the centres needs to be as little as 10^{-22} cm., millions of times smaller than the diameter of an electron. The argument with considerable masses is also absolutely conclusive against the identification of cohesion with Newtonian gravitation.

A brief consideration of the various hypotheses follows :—

(1) THE NEWTONIAN GRAVITATIONAL HYPOTHESIS.

As just mentioned, it is comparatively easy to disprove Kelvin's hypothesis which regards cohesion as simple Newtonian gravitation, although de Tunzelmann, even as late as 1910, adopted it in preference to an electro-chemical hypothesis in a work specially devoted to electrical theory.

(1) In the first place, were this true, then the vertical cohesion of the surface materials of the earth could not exceed the stress due to the weight over any horizontal area considered, since the two forces would be identical.

(2) Secondly, it would follow that cohesive force over unit area would vary positively with the volume, so that the tensile strength per unit area would be greater for large pieces than for small ones.

(3) Thirdly, it will be found that in order to produce cohesive forces of the magnitude actually observed, prodigious gravitating masses are required. This is true, even although all the molecules affect each one appreciably, as is the case with the Newtonian factor.

(4) The weight of colloidal particles in a suspension is neutralised by molecular forces of very feeble character, possibly such that each particle (containing, say, 10^9 molecules) is affected by only one or a few inter-molecular bonds.

(5) The only case in which gravitation can produce stresses comparable with those which actually exist in material is at considerable depth in a large mass. At a less depth solids are liable to be crushed if there is space for lateral motion, and, at a somewhat greater depth, the crystallising forces are neutralised so that atomic structure may be there modified by the pressure apart from temperature considerations.

This disparity of intensity between gravitation and cohesion is of great importance, and has not been sufficiently emphasised. Whether one can go further and say that there is no relation at all is a difficult question. Such an assumption would divorce gravitation from its only analogue. Sutherland's theory of gravitation as due to a fundamental excess of attraction between unlike charges over the repulsion if like charges appears to be a mere shifting of the onus on to the electrons without explaining anything.

(2) THE KINETIC HYPOTHESIS.

Tolver Preston had a theory that cohesion was due to kinetic energy. Except in so far as an invariable electro-magnetic field might be regarded in this way, such an idea is at once disproved by the fact that cohesion varies in an inverse manner with temperature, and is apparently a maximum at absolute zero.

(3) Hypothesis of an Unique Energy.

This is a very reasonable idea, but its probability is reduced by the consideration of Occam's razor (*i.e.*, the argument from simplicity). If one could show that cohesion was always positive and followed the inverse square law at all distances, it would be true.

(4) Electro-chemical Hypothesis.

Since cohesion is a paramount property of solid crystals which consist of atomic lattices, it is reasonable to suppose that the force of cohesion is only one phase of the interatomic force of chemical affinity. This latter is known to be partially if not wholly electrostatic. Some difficulties arise, however. If atoms are capable of forming bonds in all directions (or, at least, with six adjacent atoms along three conjoint axes), it is difficult to understand why free molecules in gases are so frequently diatomic. This problem is still more complicated if we regard the atomic bonds as taking place through as many free electrons as the valency number. Abegg, has, it is true, suggested that there are altogether eight possible valencies, and Thiele has postulated " partial valencies " to account for certain anomalies of stereo-chemistry. Stark has also conceived an atom which has from one to eight free electrons polarizing its surface. A further difficulty lies in the electron theory. This postulates unit charges of $4 \cdot 8 \times 10^{-10}$ e.s. units, the loss or gain of which causes positive or negative charge or, in the case of individual atoms, chemical affinity. Seeing, however, that chemical affinity varies greatly as between elements (as measured by contact potentials, the product of which into a small integral number of charges, according to the valency, gives the energy of association or dissociation), we must suppose that the electrons are differently situated in different atoms and pairs of atoms.

As has been shown elsewhere, cohesive attractions are of the order of one hundredth or more of interatomic attractions, and we can only suppose that there is a stray field at small distances due to the noncoincidence of otherwise neutralising charges, or that the atom has other weaker (? more deeply seated) charges. Sutherland has conceived that molecules consist of doublets, whose mutual attraction (like that of small magnets) is the source of cohesion. The difficulty here is that there is an equal likelihood of repulsion if the doublets are oppositely presented. If, on the other hand, the positive and negative charges are supposed to act centrally in the atoms, certain cohesion configurations can be conceived without any external field. (The phenomena of cohesion may thus help to explain the constitution of the atoms.)

When it is considered that the cohesive attractions reduced to molecular terms are of the order of 10^{-6} dynes, and the chemical forces are of the order of 10^{-4} dynes, there is an unadvoidable tendency to regard the cohesive attractions as marginal (differential) effects of the chemical forces. Similarly, when it is considered that pure elements (even if zero valency) exist in the solid form some measure of identity of cohesion with secondary valencies seems certain.

Griffith (Royal Soc., Feb. 26th, 1920) has indicated that cohesive strength is largely dependent on the orientation of the molecules, which at once makes cohesion related to the crystallizing forces.

(5) ELECTROMAGNETIC HYPOTHESIS.

The effects of electromagnetism in surface tension are considerable. It has also been shown by Svedberg that, in a fluid, complex chain molecules set themselves parallel or athwart the field. Langmuir has also found from chemical considerations that the surface molecules in complex organic liquids are oriented towards the surface so that surface tension is due to congruous configurations of molecules, and its modification by electromagnetism indicates a cognate character.

Attention has recently been called to the ring electron or "magneton" as an element of atomic structure, and it is conceivable that the atoms may have definite magnetic fields which produce cohesion, while their electro-static fields cause chemical affinity.

A strong argument in favour of cohesion being electromagnetic is provided by the very existence of fixed magnetism. It is argued that all molecules are similarly magnetic, but with dispersed polarity (as in a piece of demagnetized iron). The only difficulty is to conceive of any arrangement of doublets which will be stable, and yet have no appreciable external field.

If this hypothesis is correct, it would appear that primary attraction (chemical affinity) is electro-static, and secondary attraction (cohesion) electro-magnetic.

There is, however, quite a possibility that both electrostatic and electromagnetic forces may play a part. The capillary electrometer shows that surface tension can be affected by minute differences of potential and some difficulty is found in explaining this on a magnetic basis.

Crehore worked out an electromagnetic theory of cohesion and gravitation some years ago which was dependent on the assumption of certain electrons having a velocity only slightly less than that of ether waves. Spectrum analysis does not confirm this hypothesis, but it may be true of the "fixed electrons" in the central parts of the atoms. The large electromagnetic mass seems an objection.

(6) ENHANCED GRAVITATION.

Almost from the time of Newton investigations have favoured a cohesion hypothesis closely analogous to the Newtonian law, but with a high index of variation (see Clerk Maxwell in Ency. Brit. on "Capillary Attraction"). Modern physics do not regard mass as of so fundamental a character as formerly, but the notion is still plausible. The main difficulty is, however, to see why two methods of joint mass action following different rules should exist, and the present writer has endeavoured to make the two continuous by making the index of variation a function of the distance. Thus,

$$t_2 = \frac{G\ m^2}{d^{2+nd_0/d}}$$

where d_0 is the value of d at absolute zero temperature, or

$$t_{2_0} = \frac{G\ m^2}{d_0^{\ 2+n}}$$

If $n = 4$ (which appears to be approximately the case)—

$t_{2_0} \propto S_0^2$ where S_0 is the maximum density.

Polarity can, perhaps, occur from this equation, since for all laws of attraction for spheres, other than the inverse square, the equivalent focus is not geometrically central.

The rate of diminution agrees well with some instances in strength of materials, but is too rapid for the gas condition. There is, however, in this case, the fact that the molecular attraction is intermittent in its action, and so may be transmitted in greater measure.

Reference may here be made to the writer's previous papers.

(7) SUB-ATOMIC STRUCTURE.

Reynolds "granule" theory and Lodge's hypothesis of constituent electrons, alternately positive and negative in close formation, involve partial explanations of cohesion, but are themselves too speculative to provide a firm basis for a cohesion theory.

CONCLUSION.

The author concludes that (1) the essentially electro-chemical character of cohesion is established.

(2) The mechanical properties of a material are therefore indicative of its chemical constitution.

(3) In spite of similarity of function the relation of cohesion to gravitation is purely empiric.

ARTILLERY FROM THE SCIENTIFIC AND ENGINEERING POINT OF VIEW.

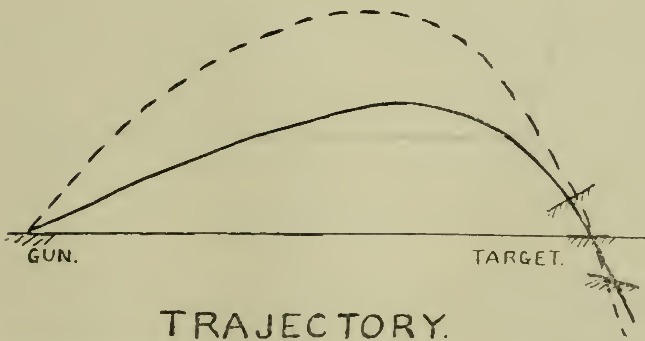
By W. Bamford, Assoc.S.E.
(Member of the Crystal Palace Engineering Society.)

This paper does not pretend to be a complete dissertation on the subject of artillery. Its object is rather to point out some of the scientific principles and some of the mechanisms, made use of in modern artillery (more especially siege artillery), which may be of interest to the engineer.

Range and Factors Affecting it.

If the case of a projectile discharged *in vacuo* be considered, it can easily be shown, by resolving the initial velocity into its horizontal and vertical components (remembering that the latter is subject to the acceleration due to gravity), that there are two angles of elevation which will give the same range, measured to a point on the horizontal plane passing through the point of discharge. Further, these two angles will be complementary, and in each case the trajectory or path of the projectile will be a parabola. In practice the resistance of the air is encountered, so that the trajectory is not a parabola, but a complicated curve, about which sufficient experimental data has been obtained to enable the Range Tables, so essential to the gunner, to be compiled. The range is also affected by several other factors, for which allowance must be made when calculating the elevation necessary to hit a given target. The wind, or rather its component along the line of flight of the projectile, will increase or

FIG. 1.



TRAJECTORY.

decrease the range, according to whether it is a following or a head wind. An increase of atmospheric pressure is accompanied by an increase of resistance and a decrease of range, while an increase of atmospheric temperature causes a decrease of resistance and thus an increase of range. Again, the occasion in which the target is on the same horizontal plane as the gun is in practice comparatively rare, and, as is indicated in the diagram (Fig. 1), the range is decreased by raising the target, and increased by lowering it. All these factors affecting the range may be said to be external, that is to say, they operate on the projectile outside the gun. There is one factor which is both external and internal, namely the weight of the shell. Externally for a given velocity, an increase in the weight of the shell increases its momentum, thereby giving it more capacity to overcome the resistance of the air and thus increase the range. Internally, this increase of weight increases the inertia of the shell, and so the same propellant force gives it a lower velocity, which results in a decrease of range. In the smaller types of ordnance the alterations in range, due to the small variations found in the weight of the shell, may be neglected; but in the heavier types the shells must be weighed and corrections applied for all such variations. Another internal factor, for which allowance must always be made, is the temperature of the charge. Such increase of temperature is followed by an increase in the volume of the gas produced upon the ignition of the charge, which results in a greater pressure behind the shell and an increase of range. The

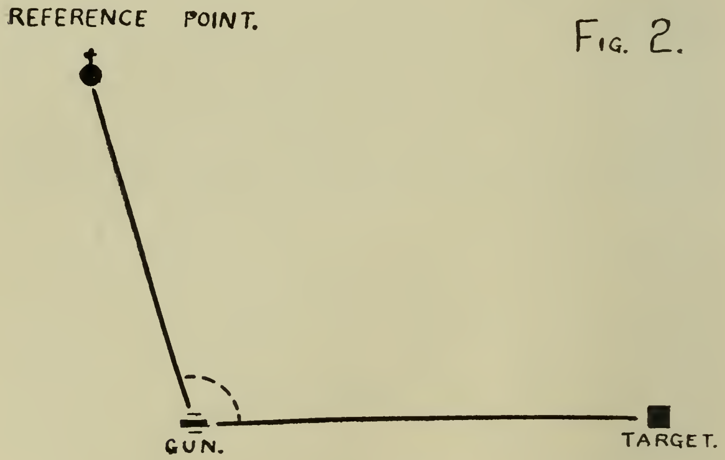


Fig. 2.

LINE.

corrections for these various disturbing factors are calculated by means of the Range Tables for the type of gun in use. These tables show the elevation for any given range under normal conditions, and also the difference in that range due to specified variations in :—

(*a*) The velocity of the wind along the line of fire.
(*b*) The atmospheric pressure.
(*c*) The atmospheric temperature.
(*d*) The weight of the shell.
(*e*) The temperature of the charge.

Knowing the actual variations in these factors, their resultant effect upon the range can be determined. The unit of the result so obtained will be yards of range, which is converted into minutes of elevations by use of another column in the range tables. The correction so found must be added to, or subtracted from, the normal elevation for the given range according as the resultant effect of the various disturbing factors is a decrease or an increase of range.

The only correction remaining is that for difference in the levels of gun and target, which is made by determining the angle between the gun-target line and the horizontal, and adding it to, or subtreacting it from, the elevation previously found according as the target is higher or lower than the gun. This angle can be determined by noting, from the map, the range and the difference between the contours of gun and target.

It must be remembered that as a shell rises to a considerable height during its flight, and as the atmospheric conditions alter at different altitudes, the mean of the atmospheric conditions along the path of the shell, and not those at the ground level, must be considered. During the late War various meteorological sections issued to all batteries, at four-hour intervals, a telephonic report indicating the atmospheric conditions for various " times of flight " (the " time of flight " being a clear indication of the height to which the projectile rises irrespective of its initial velocity or the type of gun).

DIRECTION AND FACTORS AFFECTING IT.

The length of range of the modern gun, and the necessity of keeping the battery concealed from the enemy, results in the target being nearly always invisible from the battery position. The gun cannot, therefore, be laid on the target by observation over " open sights," and other means of laying for line have to be devised. A common method is by use of a " reference point " and the " dial sight." The dial sight is an optical instrument, by means of which the angle between the line from the gun to the reference point and the line along which the gun is laid can be measured. The method of procedure is to select a suitable reference point, which must be distant, well-defined, and clearly marked on the map—for example, a church spire—measure on the map the angle between the lines reference point-gun and gun-target, set this angle on the dial sight, and swing the gun round laterally until the cross hairs of the dial sight appear to cut the reference point. The gun is then, theoretically, laid for line. In practice, however, errors creep in through the position of the gun not being accurately resected, or the reference point not being accurately marked on the map, or the reference point angle not being measured from the map with sufficient accuracy, so that the gun must be "registered;" that is to say, a series of rounds must be fired with visual observation from either an aeroplane or an observation post, preferably from two or more observation posts, so that cross-bearings can be obtained on the bursts. By seeing where these rounds fall a correction can be given to the reference point angle which will bring the line of fire on to the target. Provided that the arc of fire is not excessive, the correction so found can be communicated to the reference point angle for all future targets.

In addition to that just indicated, there are two other corrections which have to be made for direction. Firstly, there is the correction for the wind, or rather its component at right-angles to the line of fire, which deflects the shell in the direction towards which it is blowing. Secondly, there is the correction for "drift," which is a deflection of the shell due to its spinning motion and which is to the right, if the rifling of the gun has a right-handed twist.

ELEVATING AND TRAVERSING GEARS.

Something being known of the factors which have to be considered in determining the elevation and direction of the gun necessary to engage a given target, the method by which this elevation and this direction are communicated to the gun can now be dealt with.

The barrel of the gun and its recoil apparatus are mounted in a "cradle," provided with horizontal trunions carried in bearings on the carriage, thus enabling the gun to turn about the trunnions in a vertical plane. In addition, that part of the carriage carrying the cradle is supported on a vertical pivot, thus enabling the gun to turn in a horizontal plane.

Motion in the vertical direction, that is, motion of elevation, is given to the gun by means of the "elevating gear," which consists of a hand wheel attached to the carriage and connected, through a spur gearing, to a pinion, which meshes with an arc-shaped rack attached to the cradle. The angle of elevation is measured by means of a clinometer.

Motion in a horizontal plane, that is, motion of direction, is given to the gun by means of the " traversing gear," which consists of a second-hand wheel attached to the carriage and connected, through a screw-gearing, to the sub-carriage supported on the vertical pivot. In the case of guns mounted on wheels, motion in the horizontal plane is also given by moving the trail laterally. In such guns, motion given by the traversing gear is limited, for if the barrel becomes much inclined to the plane at right-angles to the axle of the carriage, great side strain is brought to bear on the wheels when the gun is fired, and, at the same time, the force, tending to turn the gun about the line joining the point of the trail and the point at which the wheel touches the ground, is greatly increased, so that there is a tendency for the gun to be thrown on to its side.

ERROR ZONE.

Having applied the various corrections, and laid the gun for line and elevation, it must not be supposed that a small target will be hit by every round fired. Slight changes in the atmospheric condition (especially noticeable in the case of the wind, which is constantly varying), back lash in the elevating and traversing gears, or in the adjustments of the dial sight ; slight variations in the position of the bubble of the clinometer, by means of which the gun is laid for elevation, and slight differences in the distance which the shell is rammed into the bore, all lead to alterations in the position of the point of impact of the shell.

As the conditions, which lead to variations of range have greater effect than those which lead to variations of direction, a large number of rounds, fired at the same line and elevation, will be found to fall in an oval-shaped area, the long axis of which lies along the line of fire. The object of the gunner is to place the mean point of impact of the rounds, that is to say, the centre of this oval-shaped zone, on the target.

THE " GUN " AND THE " HOWITZER."

The word " Gun," as usually used, includes all types of artillery, but, technically speaking, this word indicates only one class of ordnance, the other class being the "Howitzer" or " Mortar." As the Howitzer is often spoken of as a weapon of high angle of fire, it is frequently thought, by those not well acquainted with artillery, that the Howitzer only uses the greater of the two complementary angles of elevation which give the same range. Now there are many Howitzers which have a maximum elevation of 45°, from which it is clear that the greater angle cannot be used. In what, then, does the difference between the gun and the Howitzer lie? It lies in their muzzle velocity, that is, the velocity with which the shell leaves the bore. The muzzle velocity of the Howitzer is less than that of the gun of the same calibre, from which it can readily be understood that, the weight of shell and other conditions being the same, the elevation for a certain range must be greater for the Howitzer than for the gun, and also that the maximum range for the Howitzer is less than that for the gun. At the same time, it is quite true that many Howitzers and Mortars are constructed to make use of the greater of the two angles of elevation, which, the muzzle velocity being the same, result in the same range; but the chief difference between the gun and the Howitzer lies in their difference of muzzle velocity.

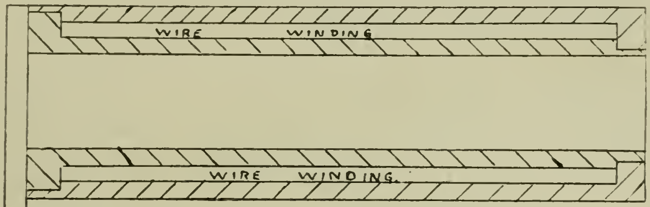
There is an interesting train of circumstances which can be traced back from this difference. The higher muzzle velocity of the gun is the result of greater pressure behind the shell, which follows from a greater volume of gas being produced in the chamber, which, in turn, is the result of a larger quantity of propellant in the charge. As the explosion of the charge is really a very quick burning, the time taken in burning the larger charge in a gun is longer than that taken in burning the smaller charge in a Howitzer. Now one of the ideals aimed at in the construction of a gun or Howitzer is so to arrange things that the last particle of propellant is burned by the time the shell leaves the muzzle; by this means there is no waste of the energy of the explosion, and at the same time there is no unnecessary waste of energy in forcing the driving band of the shell through the bore. So that the longer period of time occupied in burning the charge in the gun results in that characteristic in its construction by which it is recognised at a glance from the Howitzer, namely, the length of its barrel.

From the foregoing remarks it is readily seen that the great point in favour of the gun is its greater range, which is essential for the engaging of the distant targets; but the Howitzer, of the same calibre, which can be utilised for engaging the nearer targets, has in its favour economy of propellant, since it uses a smaller charge; a longer life, since it has to withstand smaller pressures; and mobility since it is lighter, firstly on account of its shorter barrel, and secondly on account of the fact that it has to withstand smaller forces, which permits of its whole construction being less strong.

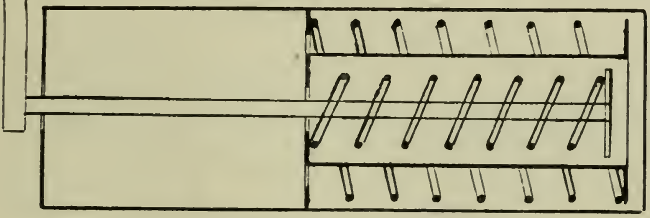
Barrel Construction.

In the old-fashioned cannon the barrel consisted of a single piece of metal, but, owing to the fact that there are frequently flaws in a large mass of metal, which cannot be discovered by an examination of the surface, the barrel of the modern gun is built up of a series of tubes and is " wire wound." This process consists of winding many miles of thin steel ribbon round one of the inner tubes, and, as every inch of this ribbon can be tested, weakness due to flaws in the metal is thus eliminated. This mode of construction also has in its favour the fact that, when the rifling becomes badly worn, the inner tube can be removed and a new tube fitted. As there is a tendency for the inner tubes to be forced forward through the outer ones when the gun is fired, the various tubes are locked together by means of collars fitting into stepped rings, as shown in the diagram (Fig. 3).

WIRE WOUND GUN. Fig. 3.



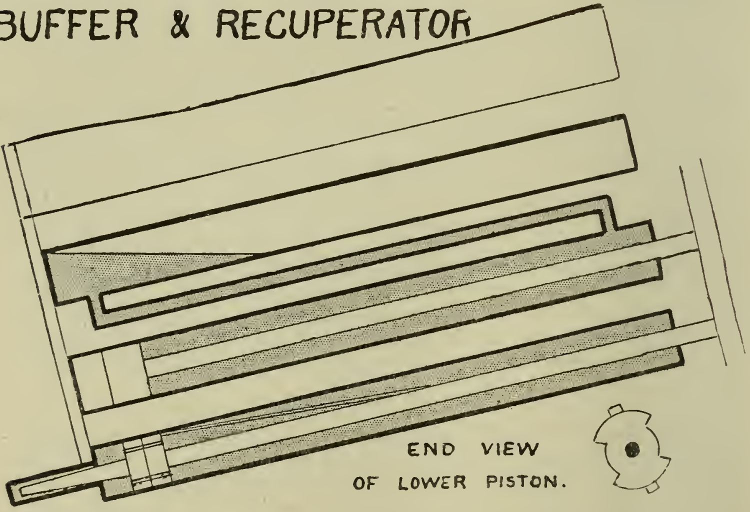
SPRING BUFFER. Fig. 4.



Recoil Apparatus.

When a gun is fired, a force, equal and opposite to that impressed on the shell, is exerted on the gun, and, to prevent undue strain, a suitable buffer to absorb this force must be provided. In some of the earlier types of gun, this buffer consists of a series of springs (Fig. 4). The barrel is fitted with longitudinal slides, which fit into grooves in the cradle, and enable it to slide lengthways. The breech is attached to a long rod, fitted with a disc at the forward end, and encircled by a helical spring, which presses against the disc in front, and in the rear against an inside flange on a tube surrounding it. This tube can move longitudinally and is held in the forward position by a second spring, which encircles it and presses against an outside flange at the front end of the tube and against a fixed part of the cradle in rear. On the gun being fired, the barrel slides back, drawing with it the rod, and compressing the springs ; the motion is thus checked, and in due course the springs resume their original shape and draw the barrel back to the firing position.

In modern types of ordnance the more efficient hydro-pneumatic buffer and recuperator is used. The diagram (Fig. 5) illustrates one arrangement of such apparatus. It consists of two parts, the buffer which checks the backward motion of the gun, and the recuperator which draws it again to the firing position. The barrel of the gun is attached to two cylinders and a compressed air chamber, and the whole is fitted with longitudinal slides, enabling it to move lengthways through the cradle. The cylinders are fitted with pistons, the rods of which are attached to the front of the cradle, and do not move when the gun and cylinders slide back.



HYDRO-PNEUMATIC BUFFER & RECUPERATOR

Fig. 5.

The lower cylinder in the diagram, which represents the buffer, is filled with oil, and the piston consists of two parts (placed end to end), one of which is fixed to the piston rod and the other is enabled to rotate about it. Two ports are cut through these parts, in such a way that, by rotating the moving part, the ports are opened and closed. Further, the moving part is fitted with lugs, which fit into spiral grooves cut in the cylinder, so that as the piston moves backwards and forwards through the cylinder, the moving part is revolved and the ports are opened and closed.

In the firing position (shown in the diagram) the ports are fully opened ; and on firing the gun, the cylinder is drawn back over the piston, and the oil is forced through the open ports from the front to the rear of the pistons, but as soon as this motion commences, the ports begin to close, so that the speed at which the oil can pass from the front to the rear of the piston is decreased and the motion of the cylinder is slowed down, until finally the ports are fully closed, and no further motion of the oil can take place, and the gun is gently brought to rest.

Now consider the recuperator, which consists of the upper cylinder (in the diagram) and the air chamber. The cylinder is supplied with a tight-fitting piston, in front of which it is filled with oil. The oil also occupies a pipe leading from the front of the cylinder to the rear of the air chamber, and a certain portion of the volume of the latter. The remainder of this volume is filled with compressed air. The gun may now be supposed to fire ; the cylinders slide back, and the piston, remaining stationary, forces the oil from the front of the cylinder through the pipe into the air chamber, where the air is still further compressed, with the result that when the motion is stopped by the buffer, the air exerts a great pressure on the surface of the oil, which communicates it to the cylinder and the piston, and so forces the gun back to the firing position.

To prevent any excessive shock due to the motion of the gun being suddenly checked on regaining its forward position, the rear end of the lower piston is fitted with a tapered plunger, which enters a small tube at the end of the cylinder, thereby forcibly displacing the oil from the tube through the ring-like opening surrounding the plunger, and as the latter is tapered the area of this opening is rapidly decreased, thereby increasing the resistance and slowing down the motion until finally the point is reached where the plunger exactly fits the tube, so that no more oil can escape, and the gun is gently brought to rest. At first sight this arrangement of drawing the cylinders over fixed pistons appears to be clumsy, but the object is to increase the weight, and so the inertia of the moving parts, which in itself absorbs a certain amount of the shock of the explosion.

SHELL.

With regard to the construction of the shell, the first point noticed is the driving band, which consists of a ring of copper firmly fixed into a groove round the shell. It carries out two duties : firstly, it is the means of preventing the escape, between the shell and the bore, of the gas generated by the explosion of the charge ; secondly, it is the medium through which the spinning motion is imparted to the shell by the rifling of the gun. The object of this spinning movement is to steady the shell in its flight, and so preserve its motion in the line along which it is intended to travel.

Up to the present, when dealing with the question of range, we have considered the shells used to be similar in design, and so have neglected the variations in range due to the construction of the shell.

The elevation, muzzle velocity and external conditions being the same, the range depends on what is called the Ballistic Co-efficient of the shell. This is given by the formula :—

$$C = \frac{W}{D2.} S.$$

Where C = Ballistic Co-efficient, W = the weight, D = the calibre or diameter of the shell, and S is a special empirical co-efficient depending on its shape. From this it is seen that the ballistic co-efficient varies directly as the weight and indirectly as the sectional area, and as a result there has been a great tendency, during the last quarter century, to increase the length and so the weight of a shell of given calibre. Thirty years ago a common length of the shell was two calibres, that is to say, its length was twice its diameter ; at the present day the lengths of some special shells are as much as six calibres.

The weight of a shell is also largely determined by the thickness of its walls and base, but, in the case of common shell, this thickness is limited by the necessity of the shell having a large capacity for the explosive mixture. At the same time, this thickness must be such that the walls and base are sufficiently strong to withstand the forces to which the shell is subjected, when it is fired from a gun. It may be noticed in passing that since a Gun uses a larger charge than a Howitzer, the walls of a shell for a Gun must have greater thickness than is necessary for those for a Howitzer of the same calibre ; so that, while a shell, intended for use in a Gun, may safely be fired from a Howitzer, a shell intended for use in a Howitzer may possibly burst prematurely, if fired from a Gun.

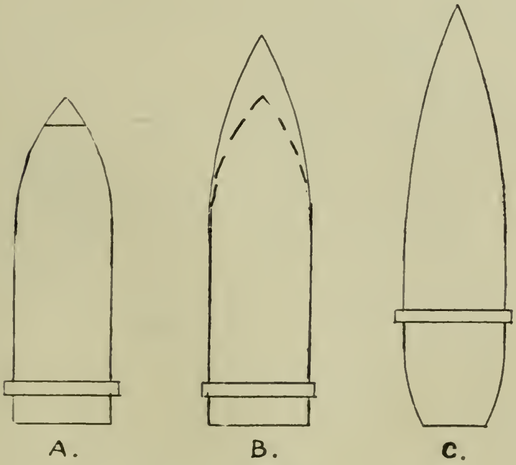
Until recent years, the most usual shape for the head of the shell consisted of a nose of two calibres radius, that is to say, the curves forming the point of a shell had a radius equal to twice its diameter (Fig. 6A) ; and it was only comparatively recently that experiments were carried out with a view to increase the co-efficient S, by making the head more pointed ; attempts were then made to alter the shape of the head of existing shells by fitting false caps (Fig. 6B), but these were not a great success, chiefly because of the difficulty of centering the cap on the shell when fitted in the field ; or if the cap were fitted at the factory, because of the tendency for it to be knocked out of centre or damaged during transit to the battery position.

In either event the result was an unsteady flight of the shell. However, in the case of a shell constructed with a head of greater radius, much better results were obtained, and during 1918 shell could be seen with eight or even ten calibre radius heads.

The latest stage in the evolution of the projectile has been reached in the " stream-line " shell (Fig. 6c), which gives even better results than a parallel sided shell of the same radius head. But with the stream-line shell difficulties are encountered, owing to the alteration necessary in the position of the driving band, which completely alters the conditions previously existing in the chamber of the gun.

Fig 6.

SHELL.



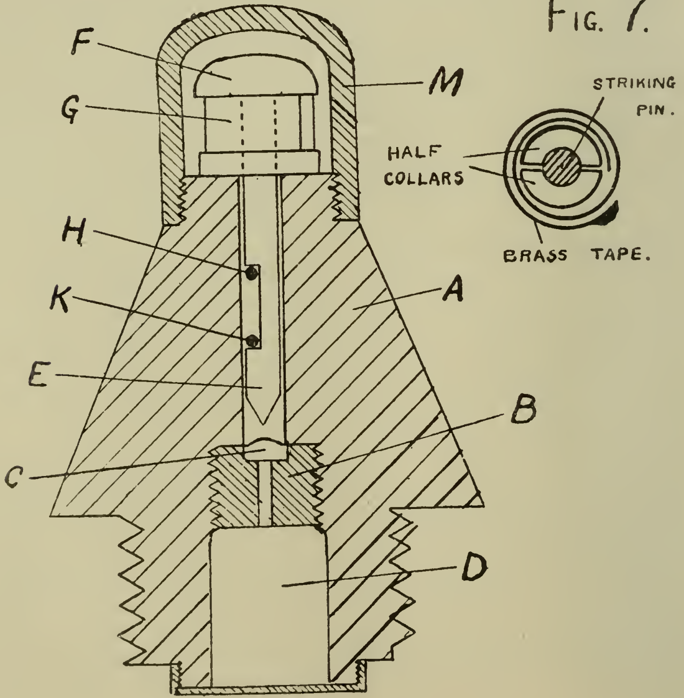
FUZES.

Fuzes may roughly be classified under the headings " Time " and " Percussion." The time fuze is that type which automatically operates at the end of a pre-arranged period after the shell is fired, and is used where an " air-burst " is required, as with shrapnel and star shell. The percussion fuze is that type which is caused to operate by the impact of the shell ; this class must, however, be divided into two sub-groups, namely, " Instantaneous " and " Delay." The instantaneous fuze bursts the shell immediately on impact, that is, before it penetrates, and is used where the explosion is required at the ground surface, as with gas and incendiary shell, or for man-killing purposes with high explosive. The delay fuze does not operate until the shell has buried itself, so that a good crater is formed by the explosion. This class is used with high explosive shell for the destruction of trenches, dugouts, fortifications, etc.

There are fuzes with many different operating systems and safety arrangements, but they all depend upon actions which can take place at four different periods. Firstly, there is the moment just before the shell and fuze are loaded into the gun, when the gunner can remove a safety cap or a safety pin, or insert a striking rod. Secondly, there is the moment of discharge, when the shell and fuze are thrown violently forward, so that the inertia of an internal movable part can cause it to "set back." Thirdly, there is the period during the flight of the shell when it travels with the spinning motion imparted by the rifling of the gun, so that centrifugal force can cause a movable part

INSTANTANEOUS FUZE.

Fig. 7.



within the fuze to fly outwards. Fourthly, there is the moment of impact, when a striking rod is forced in, or, motion being suddenly checked, the momentum of an internal movable part can cause it to fly forwards.

A typical example of an INSTANTANEOUS FUZE is illustrated in Fig. 7. It consists of a main body (A) into which is screwed the plug (B), carrying the ignition cap (C); from this a flash hole passes through the plug to the magazine (D). Above the ignition cap is the striking pin (E), at the top of which is the hammer head (F), which is prevented from descending by two half collars between the under side of the hammer head and the top of the body of the fuze; these half collars are retained in position by a length of flexible brass tape (G), having a small weight attached to its outer end. The striking pin is further held in position by a fine copper wire (H), and a steel guide pin (K), and is protected by the safety cap (M).

Action—Before loading, the safety cap is removed. During flight, centrifugal force acting on the weight at the end of the brass tape (G) causes the latter to unwind, freeing the two half collars, which fly off. On impact, the hammer is driven in, shearing the copper wire (H) and firing the ignition cap, which flashes into the magazine and causes detonation of the charge in the shell.

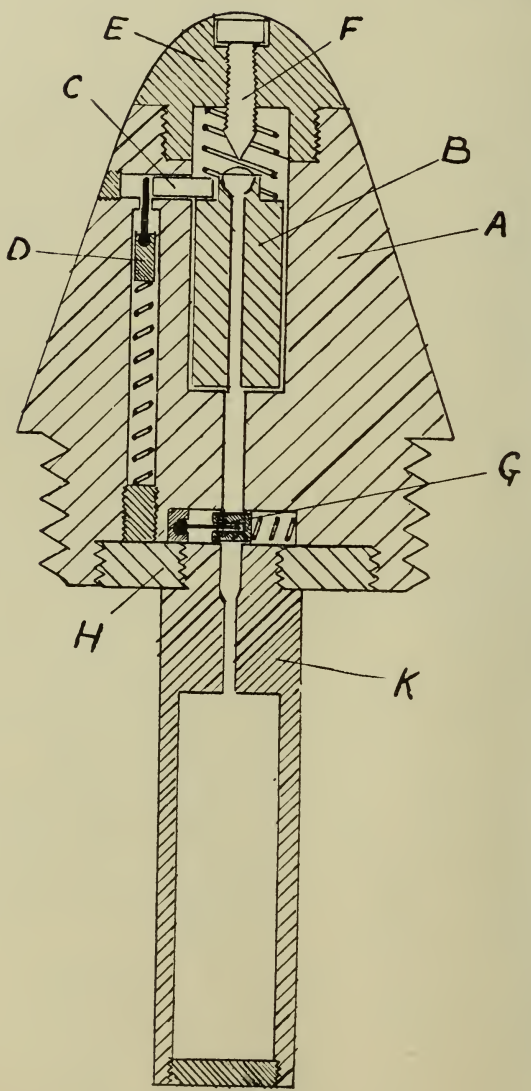
Fig. 8 illustrates a DELAY FUZE, which consists of the main body (A) bored out to receive the graze pellet (B) at the top of which is the ignition cap. The graze pellet is retained in position by the centrifugal bolt (C), which is itself held in position by a pin, the round head of which is loosely socketed into the small cylinder (D). The cap (E), carrying the firing pin (F), is screwed into the top of the main fuze body; the graze pellet and the firing pin being further separated by a creep spring. A flash hole leads through the graze pellet to the base of the fuze, where it is closed by the safety shutter (G). Into the base of the fuze is screwed the adaptor (H), carrying the Gaine (K).

The Gaine consists of a metal cylinder bored out from both ends, the top cavity containing a pellet of delay composition and the bottom cavity forming a magazine, the two cavities being connected by a flash hole. One object of the Gaine is to delay the bursting of the shell, but it also effects more reliable and more complete detonation.

Action.—On discharge from the gun the weight (D) sets back compressing the spring behind it and withdrawing the pin; the top of this pin falls to one side and so prevents it from returning to its original position; the centrifugal bolt (C), thus freed, slides outwards freeing the graze pellet (B), which, however, is prevented by the creep spring from any tendency to move forward on to the firing pin. At the same time the safety shutter

DELAY FUZE.

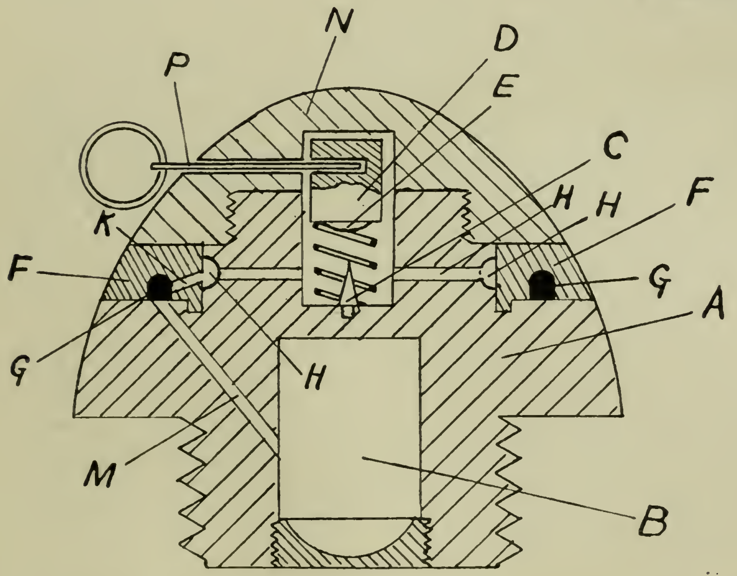
FIG. 8.



(G), under the action of centrifugal force, flies outwards, and is prevented from returning by the ball-headed pin falling to one side (thus acting like a pawl). On impact the graze pellet flies forward compressing the creep spring and driving the ignition cap on to the firing pin, thus causing a flash to pass to the gaine, which delays the final detonation sufficiently to allow the shell to bury itself and so have a good crater effect.

TIME FUZE

Fig. 9.



A TIME FUZE is illustrated in Fig. 9. It consists of the main body (A) bored out below to form the magazine (B), and above to receive the firing pin (C) and the pellet (D) carrying the ignition cap (E). The body of the fuze is turned to receive the time-ring (F), which is grooved to carry the ring of slow burning composition (G). A flash channel (H) leads from the ignition cap chamber completely round the main body immediately within the time-ring; from this channel one flash hole (K), through the time-ring, leads to the slow burning composition; also one flash hole (M), through the body of the fuze, leads from the ring of slow burning composition to the magazine. On turning the time-ring the flash hole (K) is moved, so that the length of slow burning composition between the two flash holes (K) and (M) is altered, and the time taken to burn this length of composition is proportionately varied. The outside of the time-ring is graduated to show the relative time taken to burn the composition between the two flash holes for different positions of the time-ring. The top of the fuze is closed by the cap (N) through which passes the safety pin (P), which securely holds the pellet (D).

Action.—The fuze is first "set" to the required time by turning the time-ring. In passing it may be mentioned that the graduations on the time-ring do not represent seconds, but increments of time which depend upon the atmospheric conditions; for these conditions, principally the barometric pressure, alter the rate of combustion of the slow burning composition, and must, therefore, be allowed for. Having "set" the fuze, the safety pin is removed, thus freeing the pellet (D). On discharge of the gun this pellet sets back driving the ignition cap on to the firing pin, which causes a flash in the channel (H), this passes through the flash hole (K), igniting the slow burning composition. During the flight of the shell the composition burns until the second flash hole (M) is reached, when a flash passes to the magazine (B), which communicates detonation to the charge in the shell.

CONCLUSION.

The excuse of the author for introducing to a body of engineers a subject which, at first sight, does not appear to lie within their sphere of action, rests on the fact that artillery plays, and will continue to play, a very important part in warfare; and as the wars of the future will be lost and won by the engineers and scientists of the contending nations, it is in the interests of the country that its engineers should occasionally consider warlike apparatus.

Without in any way disparaging the strategy of our generals, or the valour of our troops, it may be said that the final result of the late war with Germany lay in our superiority in material; so that, while our engineers were continually engaged on the production of more efficient equipment, those of Germany were largely occupied in the construction of substitutes for articles, rendered unprocurable through the absence of supplies of various commodities.

COAL AND ITS BY-PRODUCTS.*

By James R. L. Allott, M.I.Min.E., F.S.I.

The author's remarks will be confined as far as possible to the subject of the paper, but it will be interesting in the first place to speak of coal as found in a Staffordshire colliery where the manufacture of coal into coke and its by-products are extensively carried on.

The coalfield is that of North Staffordshire. one of the richest in the world, and from a geological and mining point of view, one of the most interesting and at the same time most complex and difficult.

The colliery is situated at the extreme end of the N.S. District. at its apex where the end of the Pennine Chain is found at the outlier of Mow Cop Hill standing 1,000 feet above the Cheshire Plain. South of this the strata dips sharply and the coal measures are abruptly brought in, so that in the short course of less than a mile all the seams of ironstone and coal are found.

Coke Ovens and By-product Plant.

There are two large batteries of coke ovens and by-product plants, but for the purpose of describing the process the author will deal with one of them, namely the "Simon-Carves" plant, with a few illustrations from another plant to complete the description of the process which is practically the same in both cases.

Fig. 1.—General View of 72 Ovens (Carl Still).

The first battery of these was erected by Messrs. Simon-Carves, Ltd., and it is interesting to note that this firm erected the first battery of by-product coke ovens in this country at Crook in the County of Durham in 1869. There are 3 batteries, of 40, 20, and 24 ovens, making in all 84, 60 of which are of the non-regenerative or waste heat type, and 24 are regenerative. Each oven takes a stamped charge of 8 tons of slack, and yields about 5½ tons of dry coke. The size of the oven is 32 feet long, 6½ feet high, 19½ inches wide at the charging end, and 20½ inches wide at the discharging end. The average coking time is about 33 hours, so that each oven can carbonize 40 tons of slack per week, yielding 27½ tons of coke.

Slack Stamping, Coke Charging, and Coke Discharging Machine.

This machine is self-contained, made by MM. Buchanan & Son, Liverpool. It is electrically operated, a 35 h.p. Mather &

---

* Read before the Wolverhampton and District Engineering Society (associated with this Society), on March 26th, 1920.

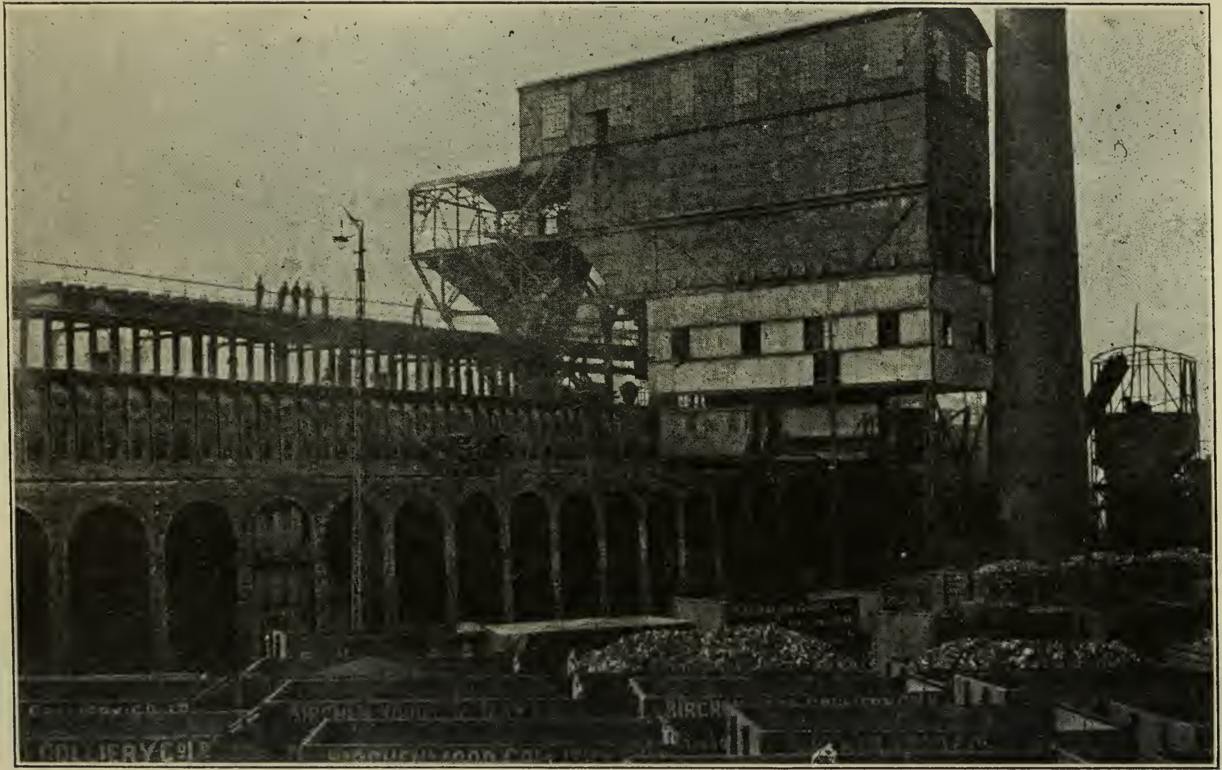


Fig. 1.—General View of the Coke and Gas Ovens Holding Plant. 72 Ovens with Bunker Holding 1,100 and one of Slack.

Platt motor being used for charging, and a 10 h.p. M. & P. motor for the stampers. From the storage bunker the slack is transferred into a stamping box on this machine where it is compressed into a heavy compact cake, weighing 8 tons. The cake is then passed into the oven by mechanical means after the coke has been discharged.

In the oven the slack is subjected to a temperature of about 1,000° C. for 33 hours, at the end of which time the ovens are opened.

When the slack is subject to the intense heat of 1,000° C. in the ovens, the volatile gases it contains are driven off and pass away by means of the ascension pipes and hydromains to large vessels called condensers. These may be either vertical or horizontal. Some vertical condensers contain a large number of tubes through which cold water is circulated and as the hot gases come in contact with the outsides of these tubes, they are cooled to the temperature of the atmosphere. At the same time, as a result of this coming there is deposited at the bottom of the condenser a black oily liquid, known as coal tar, also some ammonia water.

Exhausters are used to draw the volatile gases from the ovens, through the hydromain and condensers, and then force them through the tar extractors which are of the Pelouze & Audouin type.

The cool and tar-freed gas is now forced up through tall towers, called scrubbers, filled with wood grids set diagonally in relation to one another. Over the surface of the grids cold water is caused to fall, and as the descending water comes into contact with the ascending gas, it absorbs the ammonia from the gas. There are several of these ammonia scrubbers, the last one being known as the clean water scrubber. The liquor running from the bottom of the scrubbers is a strong solution of ammonia in water and is called Ammoniacal Liquor. This is collected in a large storage tank to await further treatment.

The cold ammonia free gas which passes from the last of the water scrubbers is now passed into other similar scrubbers, but instead of using water, which has a strong affinity for ammonia, creosote oil, which has an affinity for benzol, is used as the scrubbing liquid. The oil passes downwards over the wooden grids and absorbs all the hydro-carbon spirit from the gas, becoming what is known as Benzolised Creosote Oil, and is collected in a large storage tank to await further treatment.

From the last of the scrubbers the gas passes through an oil catcher to free it from oil and thence, as spent gas robbed of its valuable constituents, is piped back to the ovens for heating the oven flues and walls.

With the non-regenerative oven there is a considerable amount of waste heat which is passed through firebrick lined tubes to the boilers.

With the regenerative oven there is a considerable quantity of spare gas which ought to be used for town lighting in all cases. It is often used for firing boilers, but can be more economically used for driving gas engines.

Working up the Ammoniacal Liquor.

The solution of ammonia in water, obtained by scrubbing the coke oven gases, is a dark brown liquid having a sp. gr. of 1·015 and containing about 1% of ammonia. It is too weak and contains too many impurities to be used for any purpose in the condition in which it is obtained, and is consequently either manufactured into sulphate of ammonia which is of such great value for agriculture, or into concentrated liquor which is used for making ammonium nitrate for explosives, etc.

To make the liquor into sulphate of ammonia, it is heated by passing it through a series of pipes heated by the hot and foul gases coming from the saturator. From this heater the liquor passes through a superheater heated by steam and then to the top tray of the ammonia still, falling gradually from tray to tray until it arrives at the bottom, or first ammonia still, and during its descent it meets an upward flow of steam which is caused to bubble through the liquid on the various trays thus driving all free ammonia out of the liquor. In the bottom portion of the ammonia still the liquor is mixed with milk of lime and overflows through a seal into the 2nd still, where the mixture falls from tray to tray meeting another upward current of steam which boils the mixture of lime and ammonia water, thus liberating all the " fixed " ammonia, the spent liquor overflowing through an automatic outlet to the settling ponds or other places for disposal of same. The ammonia gas and steam rising up to the top of the still escape through an outlet pipe and are conveyed into a saturator.

In the saturator the ammonia gas is caused to combine with sulphuric acid to form a salt of sulphate of ammonia. As this formation of salt proceeds, it crystallises from the liquid and falls to the bottom of the saturator box, and is blown out by steam on to a draining table where all superfluous acid is separated from the salt and runs back into the saturator. The salt is then placed in the basket of a centrifugal dryer in which it is " whizzed " and then conveyed into the store room to be bagged for sale.

If concentrated liquor is to be made instead of sulphate of ammonia, gas and steam from the still is led into large cast iron vessels fitted with lead coils through which cold water is flowing. The steam becomes condensed to water which dissolves the ammonia thus forming a strong solution containing 17% ammonia. Compared with the weak solution 1% ammonia from which the concentrated liquor is made, it will be seen that the treatment concentrates the solution 20 times, and therefore reduces the cost of transport in proportion.

Working up the Benzolised Creosote Oil.

The creosote oil passing away from the scrubbers contains about 4/5% of benzol, and to extract the benzol the oil is subjected to a distillation process similar to that for ammonia liquor, the vapours being condensed in water-cooled apparatus. The cooled liquid consists of crude spirit mixed with water, and is passed into a separator where the water settles to the bottom, and is run off, whilst the lighter spirit remains on the top, and can be continuously run off to the storage tanks.

The crude heavy oil, after being freed of the benzol, is passed through coolers, and again put into circulation.

The crude benzol thus obtained consists of benzene, toluene, xylenes, naphthas, along with impurities such as pyridene, thiophene, carbon disulphide, creosote, naphthalene, and pitchy substances. Before any of these fractions can be employed in the useful arts it is necessary that the impurities should be removed and that they should be further refined.

The Rectification of Benzol.

The crude benzol is first redistilled in a vessel holding 7,500 gallons, fitted with a column for fractionating. In this vessel or still the crude benzol is heated by means of steam coils to different temperatures, thus separating the mixture into its component parts. Now all these substances have different boiling points, for example, water boils at 100° C., but benzene boils at about 80° C., toluene at 110° C., and the xylenes at 135-145° C. and upwards. Naphthalene boils at 218° C., and creosote oil at a higher temperature, and so by heating up this mixture of hydrocarbons known as Crude benzol first to a temperature of about 85° C., all the benzene comes off first, and can be collected in a separate storage tank. Then by raising the temperature to 115° C. all the toluene can be got to boil over, and to 160° C. all the xylenes. It should be noted that although these light spirits are driven off, the impurities, naphthalene and creosote oil, are left behind in the still. These impurities are worked up into whizzed naphthalene and clear creosote in a separate building.

Washing.

The spirit thus obtained is still very impure, and requires to be chemically washed. This is carried out in large cast-iron vessels fitted with mechanical agitators. The capacity of the vessels is about 3,700 gallons.

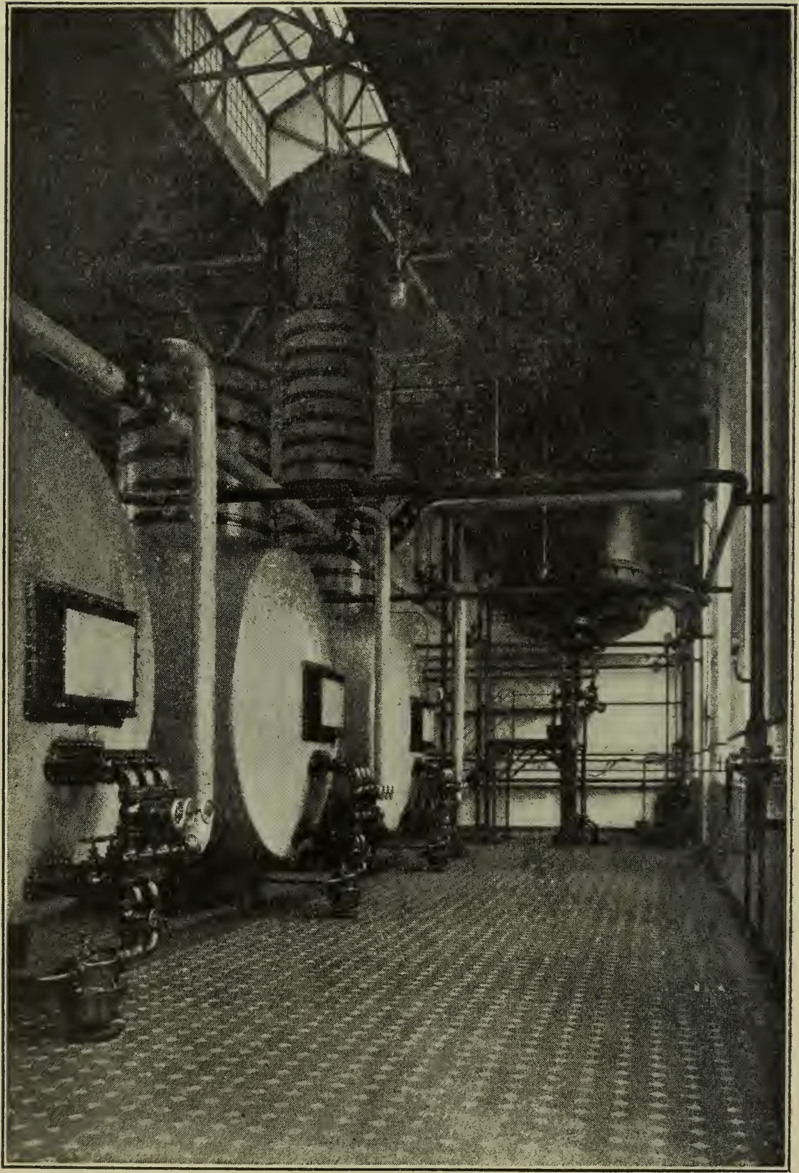


FIG. 2.—VIEW OF BENZOLE RECTIFICATION PLANT. FRONT OF STILLS WITH WASHERS BEYOND.

The once-distilled spirit is mixed with sulphuric acid (concentrated oil of vitroil) and washed, the acid being run off and the spirit again washed with water to remove the spent acid. It is then treated with one or two further washings of soda solution, and finally with water. This treatment removes from the spirit some ammonia, pyridene, tar acids, and the remaining resinous substances. The spirit is still, however, not sufficiently purified. It is therefore redistilled in another still fitted with a fractionating column and dephlegmator. This apparatus is to control the temperature of the vapours during distillation so that nothing is allowed to escape except the quality of spirit required.

The benzol stills, condensers and separators are water-cooled vessels for condensing the vapours from the stills, and the separators are for separating the spirit from the water.

There are large storage tanks, 30 ft. × 8 ft., twelve in number, each holding 11,000 gallons, and have a total capacity of 132,000 gallons.

In all these processes it is necessary to check results by frequent tests and the work of the chemist is an important factor.

Distillation of the Tar.

It will be remembered that the result of cooling the hot gases from the coke ovens was to extract the tar, which is a complicated mixture of many valuable substances, but before these can be of any use they must be separated from each other.

The separation is effected by means of distillation in large stills having a capacity of 20 tons, and to facilitate the process the tar should be dehydrated, or freed from water. This can be done either by treating with steam or utilising the heat of the vapours of distillation and partially condensing them. There are two 20 ton stills, one above the other ; the lower one is the still proper, which is gas-fired, and the upper still is the one in which the hot vapours pass through a large coil to dehydrate the tar contained therein, ready for the next distillation. The stills can either be fired with solid fuel or gas, but towards the end of the distillation steam is always used in an interior coil for better control. In this operation of distilling, like others, advantage is taken of the different boiling points. A good thermometer is therefore inserted so that the temperature of the contents can be watched.

The first vapours which pass off at a temperature from 88° to 170° C. are a little ammonia water and some light spirit. At 170° C. practically all the light oil has passed off. The receiver into which the distillate has been flowing is now changed, and the temperature increased steadily to 230° C. during which time the middle oil is distilled off, and run into a second receiver. The temperature is then increased from 230° to 270° C. to get off the

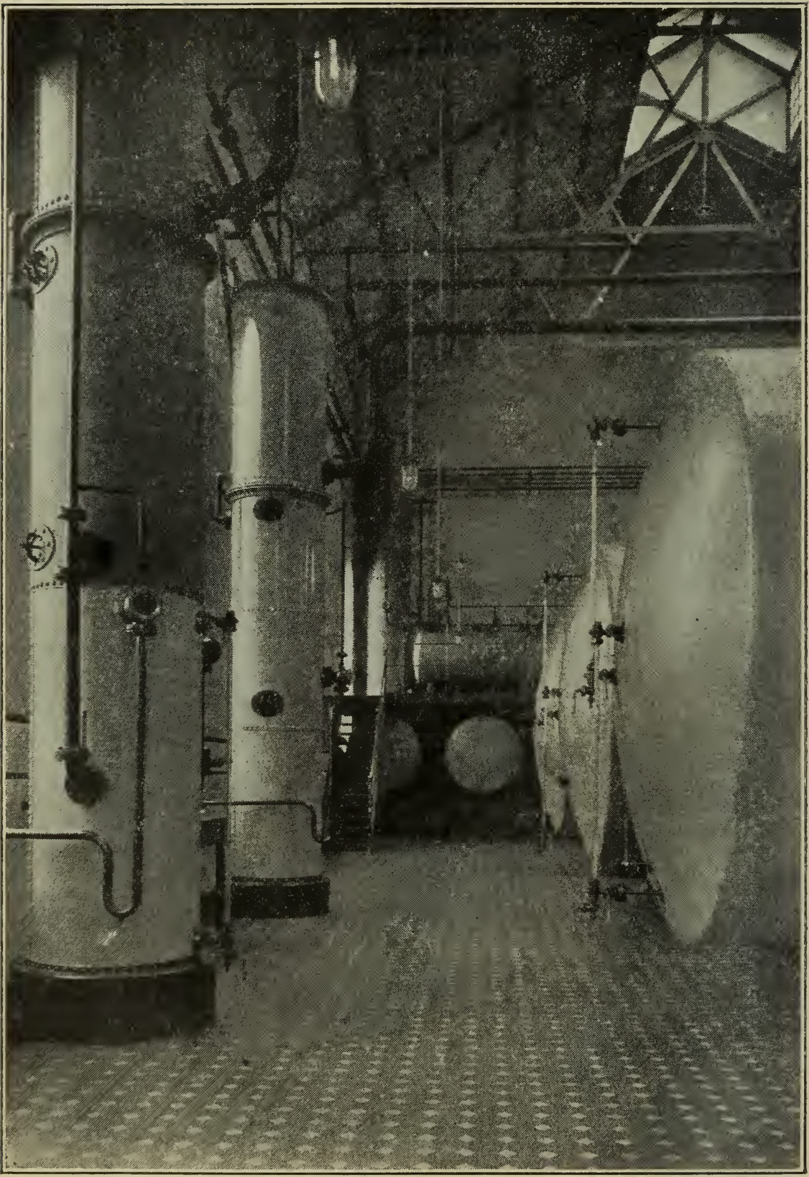


Fig. 3.—View of Benzole Rectification Plant, Back of Stills and Condensers.

creosote oil, which is run into a third receiver. The temperature is again increased above 270° C. to get off the heavy or anthracene oil, which is run into a fourth receiver, and during the time the anthracene oil is coming off steam has to be added to the still.

Instead of running the condensed liquids direct into receivers it is better to run them into pans to allow naphthalene and anthracene crystals to settle out before running the oils into the receivers.

SUMMARY.	*Temperature at which they are distilled.*
Ammonia liquor	Up to 100° C.
Ligut oil	,, 170° C.
Middle oil	Between 170° C. and 230° C.
Creosote oil	,, 230° C. ,, 270 C.
Heavy or anthracene oil	,, 270° C. ,, 350° C.

The tar distiller knows by experience when to stop the distillation somewhere between 300° C. and 350° C., according to the quality of the residual pitch required which is left in the still a little while to cool.

It is then run into a large cooler.

The cooler may be an old boiler lined with brickwork, where the pitch remains until it has been considerably cooled but is still hot enough to remain fluid. It is then run out into large shallow brick pits, the sides and bottom of which have been washed with lime to prevent sticking. In these pits the pitch quickly sets hard, and when cold is dug out and loaded into trucks ready for shipment for use in various industries.

CARBOLIC AND PYRIDENE PLANT.

In this building the middle oil from the tar distillation plant is washed and distilled for the manufacture of 60's carbolic and cresylic acids, two products used largely for disinfecting purposes and making sheep dip. Pyridene is also made, one of its uses being to adulterate methylated spirits and render it unfit for drinking by its vile odour and taste.

NAPHTHALENE PURIFICATION PLANT.

The naphthalene which is recovered at the benzol rectification and tar distilling plants is purified here. It is received into a cylindrical vessel fitted with steam coils, melted and distilled in a still similar to a tar still, the distillate being run into shallow pans and allowed to cool. When cold the naphthalene separates out as brown crystals, and the oil is run away from these. The crystals are then dug out of the pans, crushed and dried by means of a " whizzer " to remove the oil completely, the naphthalene passing into another tank, fitted with steam coils. It is again melted and pumped into a cast-iron still in an oil jacket, like a glue pot in water, to prevent direct heat on the still. It is then distilled a second time with acid, and the distillate collected in a receiving tank. It is once more melted, pumped into another jacketed still, and distilled with soda a third time. The vapours of naphthalene are now practically pure, and are condensed and run into shallow pans as before, where the naphthalene quickly solidifies into a beautiful white cake. This is broken up, crushed, and loaded into casks ready for sale.

The By-Products from Coal.

It is a remarkable fact that every one of the products of the carbonisation of coal are either themselves of the greatest service in the useful arts, or serve as the raw material from which a vast number of almost indispensable substances are made. The great iron producing industry depends entirely on the use of the residual coke as fuel for its blast furnaces. Some 8½ million tons of coke are used for this purpose annually. The ammoniacal liquor is the source of the useful fertiliser sulphate of ammonia. From the coke ovens of this country alone there are obtained no less than 150,000 tons of this product per annum.

The importance of the crude benzol recovered from coke oven gases may be understood, when it is stated that there are upwards of 30,000,000 gallons produced per annum. The amount of coal tar obtained from coke ovens reaches the enormous figure of 91,000,000 gallons per annum.

In a brief reference of this kind it would, of course, be impossible to describe at any length the manifold purposes of all the substances produced from the carbonisation of coal, but it may be of interest to mention a few of the most important ones. From coal tar some 200 different bodies have been separated, and from these again many thousands of medicinal products, explosives, dyes, perfumes and photographic materials have been obtained.

Explosives.

To begin with, these substances which have been of such paramount importance during the great War, are mostly obtained from coke oven and gas works sources. This applies not only to the explosive hydrocarbons themselves, but also to the ammonia compounds which are mixed with them. Benzene is converted by treatment with heat, acid, and alkalies, into the well-known explosive picric acid or tri-nitro-phenol, as it is more correctly called. This is the explosive forming lyddite, so called from Lydd in Kent, where it was first made.

Toluene also is the starting substance for the manufacture of

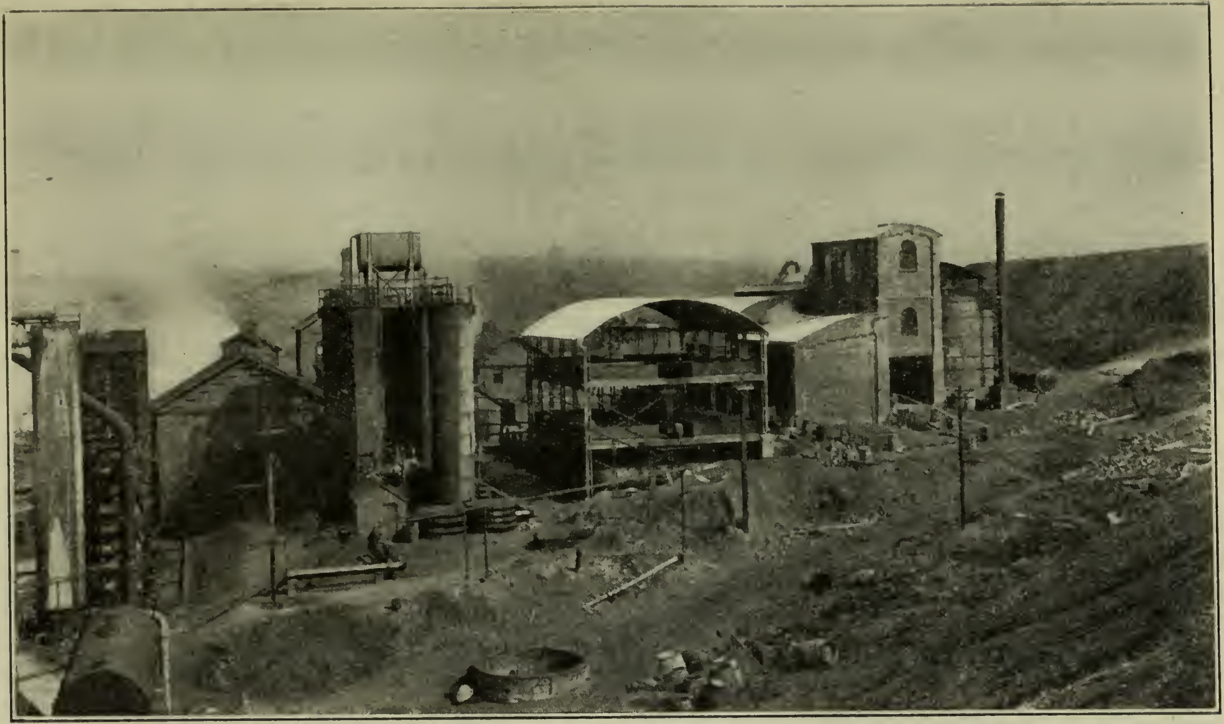


Fig. 4.—General View of Naphthalene Plant and Tan Distillation Plant (On Right). With Gas Coolers and Scrubbers on Left.

the most important explosive called trytol, or T.N.T., the proper name of which is tri-nitro-toluene.

It should be understood that these hydrocarbons are of explosive value because of the enormous store of pent up energy they contain in the carbon and hydrogen of which they are composed. Of themselves they are not explosive; indeed, they may easily be burned whilst held in the hand, but when other substances containing large quantities of oxygen are mixed with them and detonated, the rate of combination of the hydrocarbons and the oxygen is so rapid and violent that enormous local pressure is set up and explosion occurs. The energy liberated when such substances are exploded is truly enormous. It is stated that from the explosion of 1 lb. of picric acid there is liberated enough energy to raise a weight of over a ton to a height of more than 100 yards. The substance most commonly employed to provide the oxygen is ammonium nitrate, the ammonia of which again comes from the carbonisation of coal.

In addition to the ammoniacal liquor obtained by scrubbing the coke oven gases, there is found in the gas mains leading from the ovens another ammonia compound, viz., ammonium chloride or muriate of ammonia. This valuable substance is used for a great variety of purposes. Large quantities are employed in the galvanising industry for preparing the sheets of iron preparatory to their being coated with zinc or tin. For electrical purposes it is also employed in batteries used for telephones, bells, etc. A most interesting use for this substance was found during the war, in regulating the discharge of mines and torpedoes at sea.

A most important use for the ammonia obtained from the liquor is the manufacture of ammonium bi-carbonate, of which large quantities are used in every home, in baking powder and self-raising flour.

Ammoniacal liquor also contains considerable quantities of cyanide compounds, which are used in the form of potassium cyanide for dissolving the last traces of gold from the crushed and washed ores at South African mines.

Benzole as Motor Spirit.

It will hardly be necessary to be reminded of the importance of benzole and toluol as a motor fuel. The recent 10,000 mile tour, promoted by the Automobile Association, positively demonstrated the superiority of benzole over petrol, proving it to be at least 10 per cent. more economical in mileage and cleaner as a motor fuel, no injurious effect being discovered on the machinery.

Huge quantities of another coal tar product, viz., creosote oil, are now being used in the Navy. The use of this oil was for

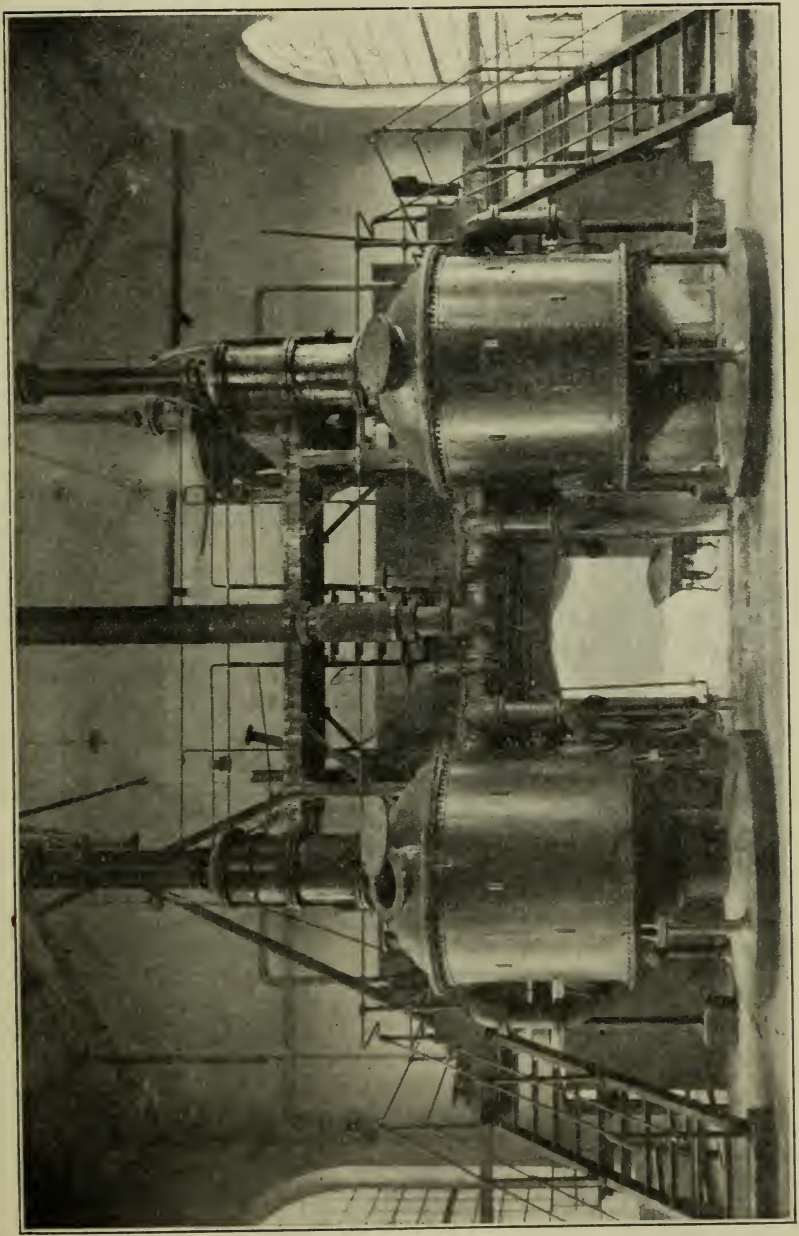


Fig. 5.—Plant for Manufacture of Sulphate of Ammonia with Sulphate Store Beyond.

many years pressed upon the Admiralty ; but it has required the national emergency of war to demonstrate its superiority to coal for maritime use.

Colours and Dyes.

Perhaps the most wonderful purpose to which the products of coal tar have been put is the manufacture of colours and dyes. There have already been some 3,000 distinct colouring matters produced. One of the most interesting of these is majenta, or rosaniline, as it is called, which is made from benzene. The benzene is first made into nitro-benzene, then into aniline, and finally, after treatment with oxidising agents, it is converted by hydrochloric acid into a beautiful red dye. By using toluene instead of benzene, and modifying its treatment, blues, greens, and violets can be produced at will.

Another of our most valuable dyes, and one of the oldest, is that of indigo, which up to quite recently was obtained from natural sources in India and China. Formerly indigo platations occupied some 1,500,000 acres, and produced about 8,500 tons of indigo, which was worth about £4,000,000 per annum. For very many years chemists attempted to produce this dye from coal tar sources, and no less than £1,000,000 was spent in the effort. Finally success was achieved, and synthetic indigo is now made on a huge scale from naphthalene. The manufacture of indigo and intermediate products from naphthalene forms one of the romances of the war. In 1914 the processes were entirely in the hands of German firms, who made a pretence of making some of the principal intermediate products in England. When the supply of these was stopped, it is to the credit of Manchester that her chemists immediately set to work, and in a short time not only indigo, but khaki dyes as well, were forthcoming in huge quantities and of great purity.

Another important dyestuff, alizarin, of which about 2,000 tons are made annually, is obtained from the anthracene of coal tar. This substance is the basis of a whole range of fast colours—reds, browns, yellows, and blues. The well known red dye known as Turkey red belongs to this class. Alizarin was formerly obtained from the roots of the Madder plant, common in France and Asia Minor. Some 80,000 tons of roots were treated annually, the value of the alizarin so obtained being £3,000,000. Naturally such a rich field attracted the attention of chemists, and it was not long before alizarin was produced from the anthracene of coal tar, which had up to then been considered valueless and a drug on the market.

The preparation of alizarin is fairly simple. The crude anthracene is first converted to anthraquinone by boiling with oxidising agents (potassium bichromate and sulphuric acid). The anthraquinone is then fused with soda and a little potassium chlorate, when de-hydroxy-anthraquinone or alizarin is formed. In use cotton is first impregnated with a soluble salt of alumina for instance, and then passed through a bath of alizarin. The colour, or "lake," as it is called, is then formed in the fibre, and gives rise to a perfectly fast pigment of a bright red colour.

Medicinal Products.

Perhaps the most valuable purpose to which coal tar products have been applied is to the manufacture of medicines and disinfectants; of the latter, Izal and Jeyes' Fluid are well known.

In 1883, *Antipyrine* was brought out for reducing the temperature of the body during fevers. It had such an enormous sale that a profit of £60,000 was made in one year.

Following quickly on this discovery came that of antifebrine or acetanilide; this extremely important substance is obtained from aniline by treatment with acetic acid (vinegar).

In 1887 phenacetine was discovered and had a great sale as a cure for headache.

Salicylic acid and salol and aspirin its derivatives are almost too well known to need description, they are all obtained from carbolic acid.

Modern anæsthetics are prepared in large quantity from coal tar sources; the following are some of them :—anesthesine, stovaine, alypine, etc. They are very useful in cases of sciatica and neuralgia.

A comparatively recent discovery may be mentioned. A famous Japanese chemist obtained in 1901, after years of labour, about a pound of a substance called Adrenaline. To get this small quantity certain glands of 20,000 oxen were required. Adrenoline has the peculiar property when applied to the skin of producing violent contraction of the arteries whereby blood is driven from the locality and bloodless surgery is possible. Immediately its value became known, chemists set to work and succeeded in making it from carbolic acid.

It is a remarkable fact that although the coal tar hydrocarbons are the source of all the violent explosions which cause such terrible wounds, yet they are also the source of the substances chiefly instrumental in curing them. For example, carbolic acid, which is one of the sources of lyddite, is also one of the most valuable antiseptics used by surgeons.

Saccharine.

It may not be without interest to mention saccharine which has recently been forced upon our notice by the national shortage of sugar. This substance is made from toluene and when pure is about 500 times as sweet as sugar.

When this artificial sweetener was first discovered the destruction of the cane and beet sugar industries was threatened in exactly the same way as the indigo and madder industries were. The Government, however, realizing that saccharine was merely a sweetener and not a food, took the matter in hand, and by restricting the sale of it for special purposes and by licensing its manufacture, prevented the threatened disaster to the sugar plantations and industries.

Perfumes.

It may not perhaps be generally known that many perfumes are now made from the products of coal tar. Almost all the natural flower odours can be manufactured synthetically in this way. Vanilla from toluene, Coumarin or Asperula from carbolic acid, Ionone, Oil of Mirbane, Hawthorn blossom, or anisic aldehyde from carbolic acid, oil of cinnamon from toluene, are but a few of these. It is interesting to note that the musk perfume, which was formerly obtained from an animal similar to young deer, is now prepared synthetically from the coal tar spirit, toluene. Its chemical name is tri-nitro-butyl toluene.

Photographic Materials.

In conclusion, it may be mentioned that some of the substances obtained from coal tar are employed in photography as developing agents. Pyrogallol, hydrokinone, metol, amidol and rodinal, are only a few of the developers obtained in this way. For the most part they are obtained from benzene and toluene, but an important developer eikonogen is prepared from naphthalene. Further, in order to ensure that the photographic dry plate will be equally sensitive to all the colours, the film is now dyed with certain colours to render it panchromatic. If the plate be required specially sensitive to greens and yellows a different series of dyes are used and the plate is said to be orthochromatic.

The exhibit of the various by-products of coal which the author has the pleasure of showing you, although numbering upwards of 100 of the most important, could really be multiplied many times.

The author is afraid he may have wearied you, but he has only touched the fringe of the subject, which is so full of interest that it may be described as perhaps the most romantic of the discoveries in science and manufacture of the 19th Century, and likely to be developed in the 20th Century to an extent that will produce results of incalculable benefit for mankind.

Note.—The patents of the German Plant have recently been purchased outright by the all British firm of Coke and Gas Ovens, Ltd., Salisbury House, London Wall.

DELAYED DISCUSSION ON

"THE PHYSICAL PROPERTIES OF CLAY."

BY ALFRED S. E. ACKERMANN, B.Sc.(Engg.).

[No. 2 JOURNAL, 1921, p. 87.]

Mr. A. L. Bell, B.A., M.Sc., M.Inst.C.E., wrote expressing his appreciation of the arduous investigation undertaken by Mr. Ackermann. Experiments so carefully carried out and accurately recorded could not fail to be useful to future experimentalists.

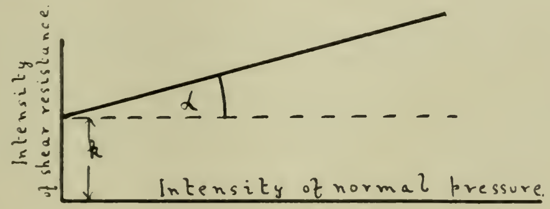
That portion of the inquiry which related to the " pressure of fluidity " had seemed to him the most interesting. His own work had not led him to conclude that, under any degree of pressure, clay would act as a perfect fluid, though clay containing a large percentage of water might approximate to the fluid condition. A perfect fluid possessed no capacity to resist internal shear, and this was not, in his view, true of clay under any conditions. He had shown that, under a head *h* the intensity of active horizontal *pressure* exerted by clay (of weight *w*) was—

$$wh \tan^2\left(\frac{\pi}{4} - \frac{a}{2}\right) - 2k \tan\left(\frac{\pi}{4} - \frac{a}{2}\right)$$

and that the maximum intensity of *resistance* to horizontal movement at the same depth was—

$$wh \tan^2\left(\frac{\pi}{4} + \frac{a}{2}\right) + 2k \tan\left(\frac{\pi}{4} + \frac{a}{2}\right)$$

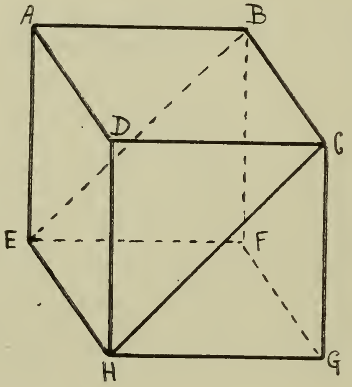
In these equations the values of k and a were those given in a shear diagram of the form indicated below :—



In a true fluid there would be, at the same point, no difference between the intensity of pressure and the intensity of resistance, to attain which condition of perfect fluidity both k and a must become zero.

In one important point Mr. Ackermann's inquiry had differed from his own in that the latter was directed towards the determination of the pressures and resistances in *undisturbed* clay—

that being the problem to which he had had to find a solution. To illustrate the point he might allude to a very simple little experiment which he had made before undertaking his published investigation. He had taken a small cube of common soap, as illustrated below :—



Holding this in one hand between finger and thumb applied respectively to the two horizontal surfaces ABCD and EFGH, he had placed the finger and thumb of the other hand on the two vertical and opposing faces BCGF and ADHE ; then exerting pressure with one hand upon the horizontal surfaces, he had noted the slight corresponding outward movement of the vertical faces felt by the finger and thumb of the other hand. This slight movement appeared to depend upon the elasticity of the material which, so far as he could judge, returned upon release of the pressure to its original form.

The next step which he took was to cut the cube through with a knife on the diagonal plane BCHE—approximately the plane of maximum shear. Replacing the fingers as before, he noted the great increase in the lateral pressure which had followed upon the destruction of the initial shearing resistance along the plane BCHE. The shearing resistances of undisturbed material under varying conditions of normal pressure, and the determination of the true position of the plane of rupture in a volume of infinitesimal dimensions, thus appeared to him to be the essential elements from which a solution might property be sought.

Mr. Ackermann had mainly experimented with, and drawn his conclusions from, clay in which he had purposely broken down this initial resistance to shear by puddling the clay, mixing it with water, etc. It was true that engineers could not limit their attention solely to undisturbed material. They had to take into account also material which had been disturbed, but as regards foundations especially the problem was one calling primarily for the investigation of undisturbed clay. He trusted that in pursuing further investigations Mr. Ackermann would devote some attention to this aspect of the matter.

Returning to the "pressure of fluidity," he thought it not improbable that what Mr. Ackermann had discovered (and it was really a very interesting discovery) was not the point of "fluidity" but the final yielding point of the material under vertical pressure. The intensity of vertical pressure under which a foundation of undisturbed clay would yield he had, using the natation given above, shown to be—

$$wh \tan^4\left(\frac{\pi}{4} + \frac{a}{2}\right) + 2k \tan^3\left(\frac{\pi}{4} + \frac{\pi}{2}\right) + 2k \tan\left(\frac{\pi}{4} + \frac{a}{2}\right)$$

Taking, for example, $k = 0 \cdot 3$ ton per sq. ft., $a = 3°$ (see p. 264, Vol. CXCIX, Proc. Inst.C.E.) and assuming the clay to weigh 128 lb. per cub. ft., it would be found by calculation from that formula that the ultimate supporting power for a head of 1 ft. would be about 1·40 tons per sq. ft., and for a head of 3 ft. (an increase of 200%) about 1·54 tons per sq. ft., or an increase of 10% due to the increase of head. This result agreed reasonably with Mr. Ackermann's 48th conclusion, and supported the view that what Mr. Ackermann had called the "pressure of fluidity" was really the ultimate supporting power.

Mr. Ackermann was to be congratulated upon his experimental proof of the elasticity and permanent set after torsion of a suspended filament of clay. He had also determined the tensile strength in certain cases. This information would doubtless prove useful. The difference between the tensile strength of rolled and extruded specimens was remarkable, and prompted speculation as to the cause.

The phenomena of the binding of clay upon a pile when driving was discontinued for a time was well known. In Mr. Ackermann's experiments this peculiar property showed itself in the decrease in the volume of clay extruded under pressure when the flow was stopped for a time by plugging the orifice. It added a further complication to a subject already sufficiently difficult.

Monday, 3rd October, 1921.

THE RT. HON. LORD HEADLEY, PRESIDENT,
IN THE CHAIR.

THE WINNING OF TIDAL LANDS IN BRITISH GUIANA.

By GERALD O. CASE, A.M.E.I.C., Assoc.M.Am.Soc.C.E., M.S.E.,
Consulting Engineer to the Government of British Guiana.

Although a considerable area of land has been won from the sea in Holland, England and elsewhere, there are, in various parts of the world, still vast tracts of tidal marshes which can be profitably reclaimed.

The author recently investigated the possibilities of reclaiming tidal marshes in the United States, and found that there alone, there were between six and seven million acres which might be profitably reclaimed. The comparatively small area which has been reclaimed is noted for its fertility. As stated by the United States Department of Agriculture, " there is no good reason why this condition should longer continue, and it is to be hoped that the American people will soon take steps to abate this nuisance and make this land contribute to the support and upbuilding of the Nation."

While the reclamation of tidal marshes in many parts of the world is becoming a question of national importance, it is also of considerable interest from an engineering standpoint, as many complicated factors have to be considered before it is possible to design a successful scheme of reclamation. It does not appear to be generally known that about 90 per cent. of the cultivated land in British Guiana has been won from the sea, and the author therefore thinks that a brief history of the reclamation works may be of interest to the members of the Society of Engineers.

British Guiana is the only British Colony on the mainland of South America ; its area is about the same as the combined areas of England, Scotland and Wales. The front lands abuting on the Atlantic Ocean in their physical features bear a close resemblance to Holland. The total length of the coastline is approximately 135 miles, and practically all of the front lands are from 2 to 4 ft. below the level of high spring tide ; they form a plain of marine alluvium which is traversed in places by lines of sand dunes; Georgetown, the capital, and practically all of the sugar estates in the Colony are several feet below the level of high tides.

Every foreshore has a natural inclination of repose, and if at the commencement of a cycle of coastline changes the gradient of the foreshore is flatter than the natural inclination of repose then, as a general rule, the sea builds up where the waves break (perhaps some distance from the upland) a barrier of sand, gravel or shell, and thus forms a foreshore at the natural inclination of repose. In places where there are gaps in the barrier, due to river outlets, the area sheltered behind such naturally sea-formed barrier, then becomes silted up, being no longer exposed to violent wave action. The flood tidal current, and in some cases the river current, bring in sand and silt which are deposited at slack water, and salt marshes or tidal forests are gradually formed. In the formation of salt marshes behind sea-formed barriers, vegetation plays a very important part. Currents bring in the silt and the vegetation organises and controls the accretion and causes it to take place at a much more rapid rate than it otherwise would. Plants and trees which grow on the sheltered area, covered at high tide but dry at low tide, slow down the currents and cause the material to be deposited which in their absence would be held in suspension and moved away. Numerous marine animals dwell among the plants, and their remains and the decay of the plants themselves assist in forming a fertile soil. The factors at work may be regarded as forming collectively a machine for building up a soil on the foreshore and reclaiming it.

The available evidence seems to prove conclusively that the last cycle of coastline changes in British Guiana was started by an alteration in the relative levels of land and sea ; uplift causing the formation of a wide foreshore covered by the sea at high tide and dry at low tide. A shell barrier was then formed and in course of time marsh land and tidal forests were formed behind the barrier.

The Dutch, who in the early days occupied British Guiana, owing to their experience of the fertility of reclaimed land in Holland, quickly recognised the possibility of reclaiming and cultivating the immense area of marsh and tidal forests which they found on their arrival in Guiana. The reclamation of the coastlands of British Guiana was commenced by the Dutch about the year 1750, and afterwards continued under British rule. If the coastlands had been left in their natural condition it is probable that the rate of erosion, due to the gradual inland movement of the shell barrier, would have been small. The empoldering of the land, however, and man's interference with the natural drainage condition, caused erosion to take place, and as a result the land-owners in the Colony for many years past have been continually fighting the sea in order to prevent erosion and the flooding of the land originally won from the sea.

In his comprehensive report on British Guiana made in 1919, the Hon. C. Clementi, Colonial Secretary, reviewing the history of the coast protection works of the Colony, states that " the adjacent proprietors emulated each other in endeavouring to divert attacks of the sea from themselves to their neighbours. So grew up an irregular and unnatural coastline in which each drainage outlet was a danger spot. Heavy expenditure was incurred by estates' proprietors upon sea defence work of useless and often harmful design. Vertical sheet-piling and stone piled wave-screens only hastened erosion, while the true angle of groynes, their proper height above the foreshore, and the importance of maintaining them in an impervious state was never understood."

When the cost of protecting an estate became more than a proprietor could bear, the line of sea dams was abandoned and retirement inland was effected without consideration being given to the consequence of such retirement to the adjacent estates. Thus the coastline grew still more irregular and the cost of protection steadily increased. In 1883, the Director of Public Works was empowered to make regulations for protecting the foreshore, to supervise all coast protection work, and, with the assent of the Government, to compel the execution of works necessary for preventing erosion. In 1906, a body of Sea Defence Commissioners were formed, with the Director of Public Works as Chairman, and all sea defences on the East Coast were vested in the Commissioners, who were given power to levy assessment to pay for work done. In 1913, the Ordnance was amended, and all sea defences were vested in the Director of Public Works, and it was provided that the Public Works Department should execute all works, and that one-fourth of the cost should be defrayed by the Government, and the remaining three-fourths by the villagers and proprietors of estates. Erosion of the foreshore, however, steadily continued, and consequently the difficulties and cost of protecting the sea dams steadily increased.

As a direct result of difficulties arising from sea defences, a number of sugar plantations were cropped and went out of cultivation prior to 1915. In that year, Sir Walter Egerton K.C.M.G., Governor of British Guiana, recognising the seriousness of the position, appointed a Commission to inquire into the Colony's sea defences. The Committee in their report state that " the numerous breaches caused by the sea have revealed the danger to the entire coastal industries of the Colony, as well as to the city of Georgetown, in this growing menace of the sea." In moving the adoption of the Organisation Committee's report on January 17th, 1916, the Hon. J. J. Nunan, K.C., said, " The emergency is too great to waste words upon it. Our inadequate and unscientific sea defences have been broken in several places within a few miles of Georgetown during the four weeks of the Commission's existence. . . . The matter is vital, no vehemence of ours on this Commission could exaggerate the importance of the issue. . . . It is also, whether we should allow the sea to encroach more and more upon the land, allow the sugar and rice industries to be ruined, and watch with equanimity until Georgetown (taken in flank) has to retire to the sandhills, and the river estates are left (and only for a short time as they now realise), the last survivors of an industry built up with brains and millions of dollars by a different type of man."

An idea of the enormous amount of money spent in attempts to combat erosion may be gained from the fact that in 1915, the annual maintenance expenditure was $276,381. In the spring of 1916, it was agreed as a result of the Commission's Report, that expert advice should be obtained on the best means of permanently defending the foreshore against erosion by the sea, and the author was engaged by the Government to make a report and prepare a comprehensive scheme of protection works.

The reclamation of large areas of tidal marsh and forest lands in British Guiana was originally accomplished by building

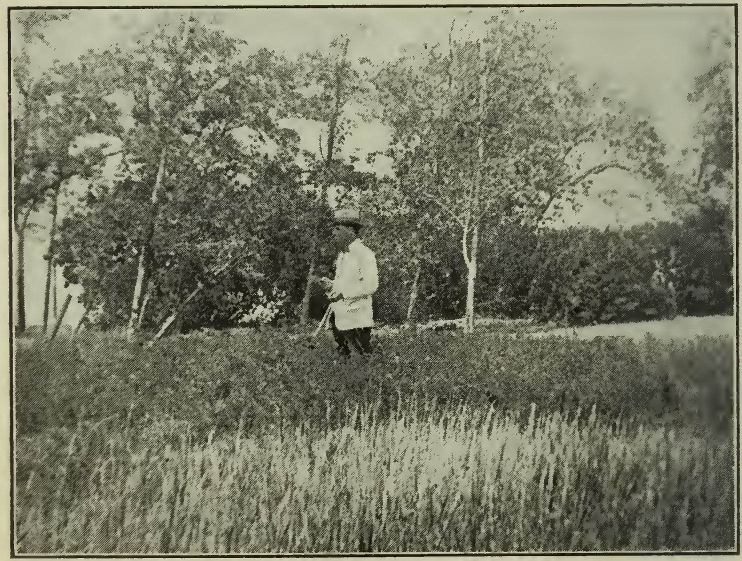


FIG. 1. TIDAL MARSH AND TIDAL FOREST. AT HIGH TIDE THE MARSH IS COVERED BY THE SEA.

earth dams a short distance behind the seaward edge of the marsh or tidal forest, the construction of dams at right angles to the sea dam up to the high land behind, or to an inner dam parallel to the sea dam. Sluices were constructed in the sea dam to discharge the drainage water at low tide (Fig. 3). When erosion took place and the sea dam was first attacked it was generally protected with fascine work (Figs. 4 and 5), and in some cases by groynes, wave-screens, and vertical piling (Figs. 6, 7 & 8). When the work of protection became too expensive for the proprietor to bear, the dam was abandoned and retirement inland was resorted to.

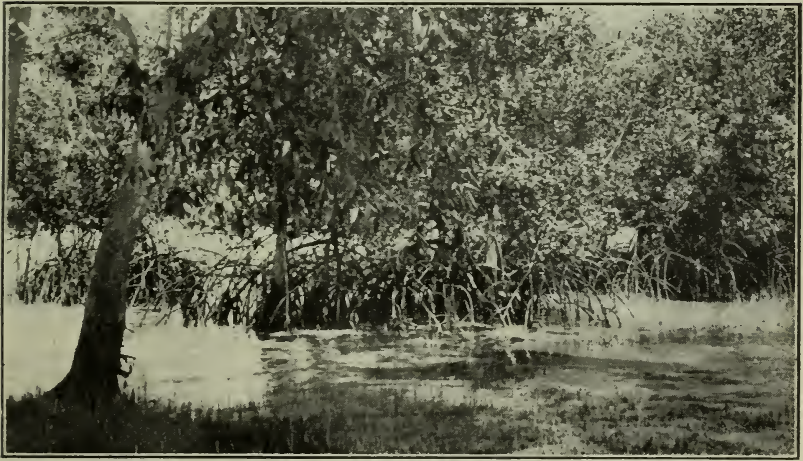


FIG. 2. MANGROVE TREES GROWING ON FORESHORE.

The erosion which has taken place in the past has not gone on at a uniform rate along the whole coast-line. A characteristic feature of the coast being the formation and progressive longshore movement from East to West of large mud-banks. While a mud-bank is in front of any particular estate little or no erosion takes place. In some instances a mud-bank would form in places where large sums were being expended on the upkeep of the sea dam, and while the mud-bank remained in front no further expenditure would be required. The section of coast between Mahaica Creek and Clonbrook is a good example of the coast-line changes caused by the formation and subsequent westerly movement of mud-banks. In the 'eighties serious erosion was taking place on this section of the coast, then a mud-bank formed, and protected the greater part of this section. In 1893 the mud-banks had moved westward sufficiently for erosion

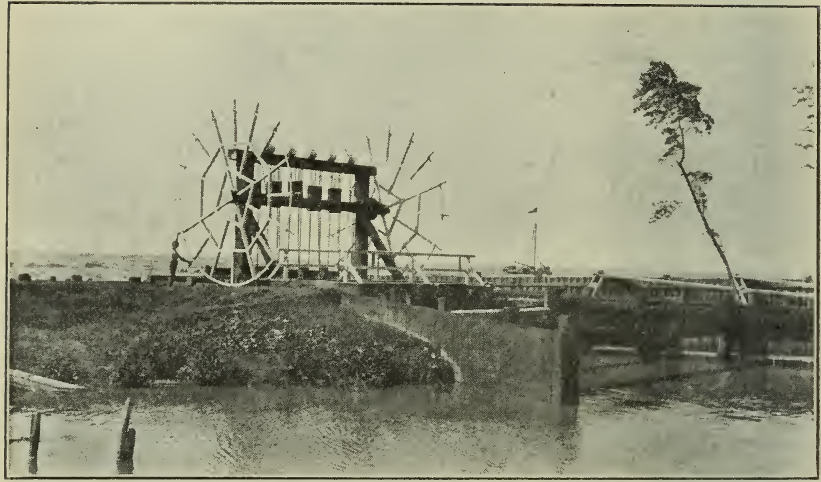


FIG. 3. SLUICE, LOCALLY KNOWN AS "KOKER."

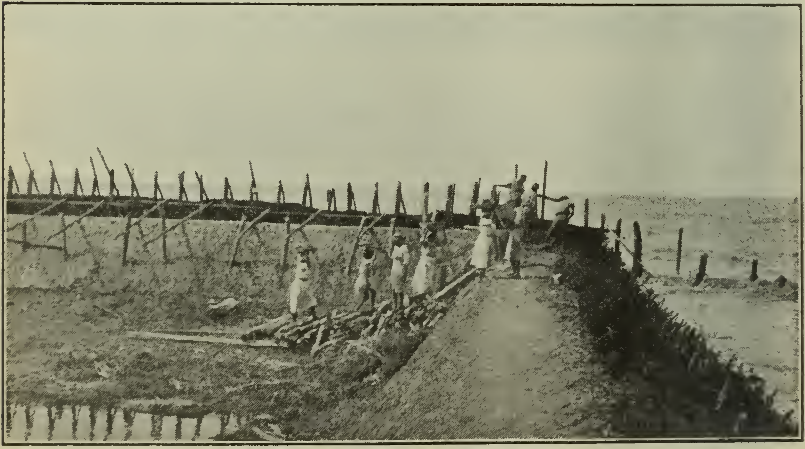


FIG 4. EARTH DAM PROTECTED BY FASCINE WORK

to again commence, and, gradually increasing in severity, it continued for some years. In 1899 another mud-bank made its appearance, and gradually moved westward, erosion being again reported in 1901. The movement of the mud-banks, although gradually westward, is erratic, and their movement in some cases is difficult to account for.

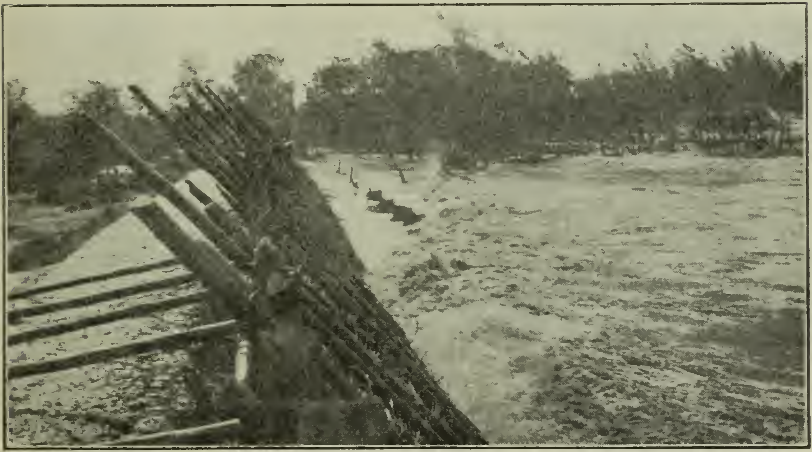


FIG. 5. EARTH DAM, FRONT VIEW.

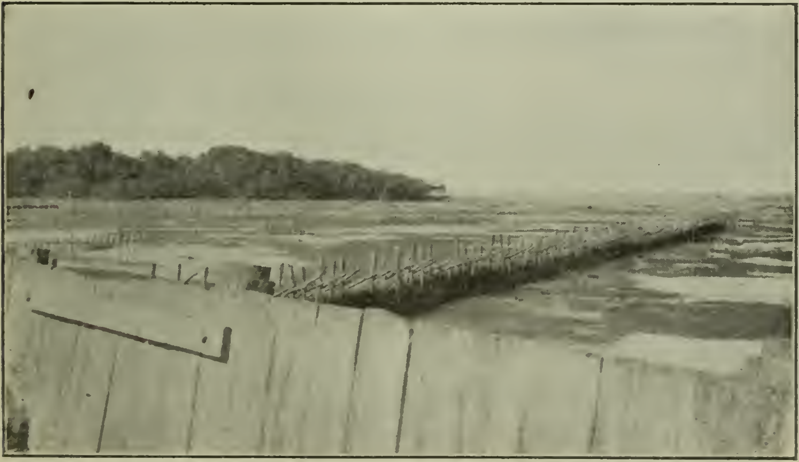


FIG. 6. FASCINE GROYNE IN FRONT OF VERTICAL SHEET PILING.

The foreshore consists largely of what is locally termed "sling mud," in some cases with deposits of "caddy" on top, and ridges of broken shell at or just above high-water line. Sling mud is a non-calcareous plastic clay containing some sand, as shown by the following analysis :—

SLING MUD.

	Per cent.
Insoluble residue (Sand)	48·68
Silica (SiO_2)	11·74
Alumina + Ferric Oxide (Al_2O_3, Fe_2O_3) ...	27·44
Lime (CaO)	nil
Magnesia (MgO)	1·88
Combined water, organic matter and loss ...	10·26
	100·00

Caddy, which in places collects on top of the sling mud, consists of fine sand mixed with clay and calcareous matter, as shown by the following analysis :—

CADDY.

	Per cent.
Insoluble residue (Sand)	68·12
Silica (SiO_2)	5·95
Alumina Ferric Oxide (Al_2O_3, Fe_2O_3)	12·34
Lime (CaO)	5·07
Magnesia (MgO)	1·18
Carbonic Anhydride (CO_2)	3·67
Combined water, organic matter and loss ...	3·67
	100·00

On some parts of the coast the upper part of the foreshore has a comparatively large amount of sand, and in places sand-ridges are to be found at high-water line which have entirely covered the artificially made sea dams. The sea water along the Guiana coast is always discoloured owing to the large amount of material in suspension in the water. Experiments made showed that during calm weather the sea water from 750 to 1,000 ft. seaward of high water mark contained from 20 to 30 grains of suspended matter per gallon of water, and during rough weather often as much as 100 grains per gallon. The maximum amount found in suspension was close to high-water line during a storm, when there were 433 grains of sediment per gallon of water. The rivers flowing from the mainland of South America to the coast of British Guiana bring down practically no material in suspension, and it is probable that the large amount of material found in

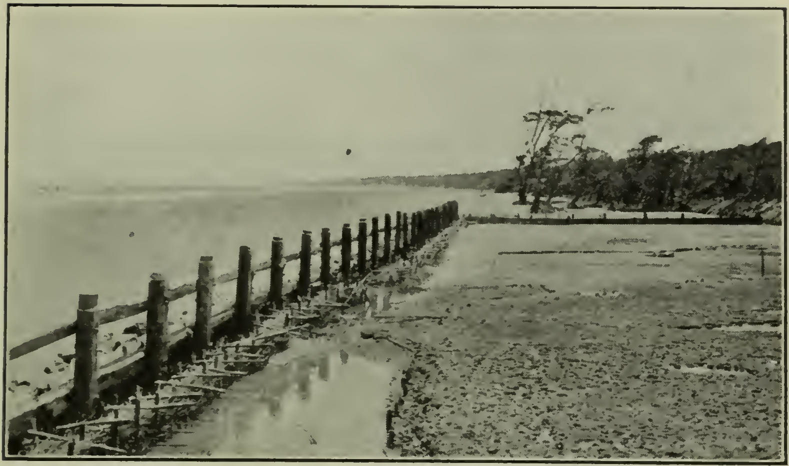


FIG. 7. STONE AND TIMBER WAVE SCREEN.

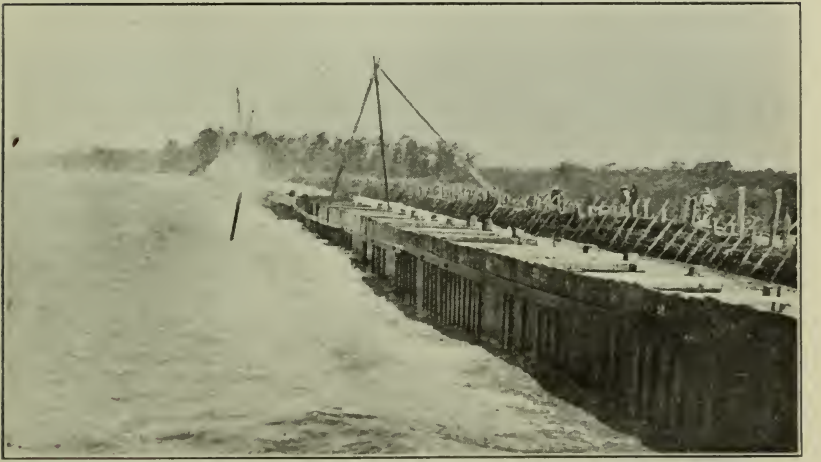


FIG. 8. VERTICAL SHEET PILING BUILT TO PROTECT SEA DAM.

suspension along the British Guiana coast comes from the Amazon River, being transported to the British Guiana coast by the prevalent littoral current.

After carefully studying the local conditions, the author came to the conclusion that the chief causes of erosion were :—

(1) The discharge of drainage water from the estates across the foreshore.
(2) Artificial works, such as vertical sheet piling, wave screens, and high groynes.
(3) Destruction of vegetation in front of the sea dams.
(4) The removal of shell from the front of the sea dams for road building and other purposes.

It was found that, as a general rule, erosion had taken place on the leeward side of the drainage channel. Where the amount of littoral drift was large and the amount of drainage water small, the damage done was unimportant ; but where the amount of water was comparatively great, serious erosion had taken place. The history of the coast shows that as the area of land under cultivation and the number of drainage outlets were increased, erosion also increased. The erosion which has taken place east of Mahaica Creek, where there are few drainage outlets, is much less than the erosion on the east coast, where there are no fewer than sixteen outlets between Georgetown and the Mahaica Canal. In a large number of cases the drainage channel, instead of flowing out straight across the foreshore, was diverted along the shore by the littoral drift, causing a channel and consequently deep water close to the foot of the sea dam.

In front of several estates vertical sheet piling was built in front of the sea dams to protect them from wave action. In his reports to the Government the author stated that severe erosion and heavy expenditure incurred in repairing breaches in a number of places was largely due to the vertical sheet piling. Wherever subjected to the action of breaking waves at high tide, the waves strike the face of the vertical sheeting and project large volumes of water into the air, which, falling at the back of the sheeting, have scoured away the earth dam, and falling at the toe of the sheeting, have scoured out the mud shore. (Fig. 9.)

Prior to 1916 large sums of money had been spent in erecting ridges of stone and stone-filled timber constructions parallel to the sea dams a short distance seaward of them. Such wave-screens not only proved a failure, inasmuch as numerous breaches occurred, and heavy maintenance expenses were incurred in repairing the dam immediately behind the wave-screen, but they have, in many cases, also caused serious erosion in front. Experience in other parts of the world, especially the New Jersey coast of the United States of America, has proved the futility of trying to protect the coast by wave-screens where active erosion is

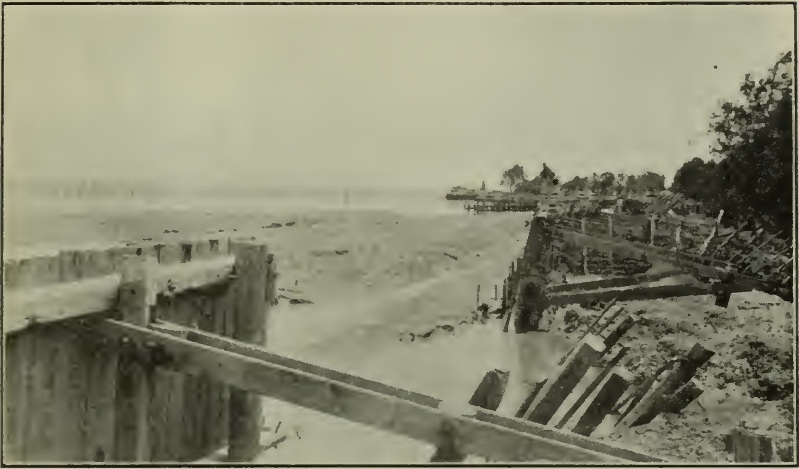


FIG. 9. SCOUR CAUSED BY VERTICAL SHEET PILING.

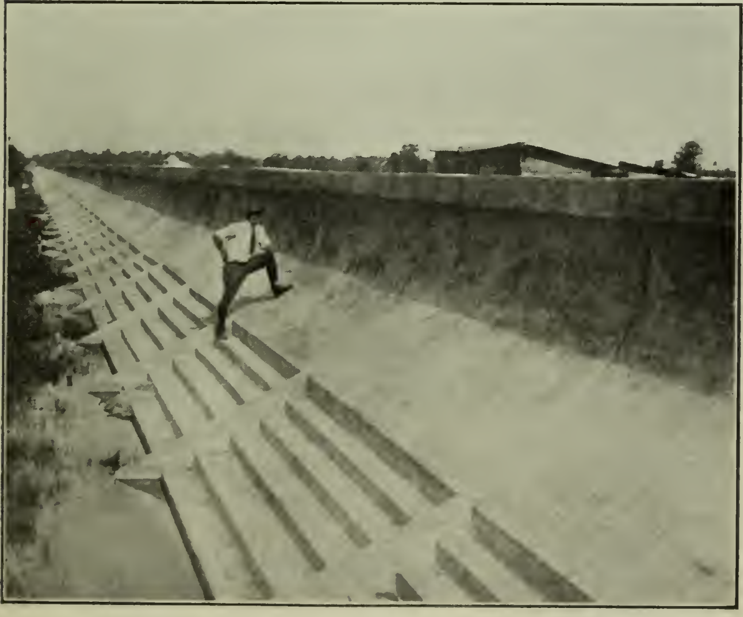


FIG. 10. REINFORCED CONCRETE SEA WALL.

taking place. On the east coast of British Guiana in all places where there were wave-screens and active erosion was taking place, the result of the wave-action was gradually to deepen the shore in front until the waves, owing to the increased depth of water, were able to break over the screen with considerable force and damage or breach the earth dam behind. The investigations made showed that on the British Guiana coast vegetation is useful in holding and building up sheltered areas of foreshore subject to overflow during high tide. Courida (*Aricennia nitida*), black mangrove (*Rhizophora mangle*), and white mangrove (*Laguncularia racemosa*) being especially useful in muddy places above the breaking point of the wave in building up and consolidating the mud. The roots of these trees slow down the currents and cause materials to be deposited which would otherwise be moved away. Although Courida and mangrove trees have proved to be useless to prevent steady erosion by wave action, their ability to build up areas above the line of breaking waves subject to overflow during high tide cannot be questioned.

Under natural conditions the tendency in Britith Guiana is for shell-banks to be formed at about high-water line, such banks forming a natural protection to the low-lying land. Prior to 1916 a considerable amount of shell was removed from the foreshore for road construction and other purposes. As the amount of shell available for building up natural protecting barriers was small, the removal of shell in the past has undoubtedly been detrimental.

After carefully considering the formation of the coast land, the changes in the outline of the coast which had taken place, the forces causing the movement of the foreshore materials, the causes of erosion and of littoral drift, and the available supply of material for building up the shore, the author advised the Government to do the following work :—

(1) Where possible to straighten the line of protecting dams by abandoning the existing outer protecting dams, and building new dams further inland.

(2) Build a reinforced concrete sea wall in place of an earth dam on the most exposed parts of the coast. (Figs. 10, 11 and 12.)

(3) Where the earth dams were liable to be attacked by wave action to face them with reinforced concrete. (Figs. 13 and 14.)

(4) Construct new reinforced concrete drainage sluices in line with the sea wall or concrete-faced earth dam. (Figs. 15 and 16.)

(5) Construct training walls or groynes on each side of the drainage outlet to guide the water direct out to sea.

(6) Construct a system of low groynes in front of all exposed sea walls or dams to build up the foreshore. (Fig. 18.)

(7) Remove all existing structures such as wave-screens, high groynes, and vertical sheet piling, which were causing erosion.

(8) Encourage the growth of suitable vegetation in front of the dams.

(9) Prohibit the removal of shell from the front of the sea dam.

(10) Prohibit the destruction of any useful vegetation.

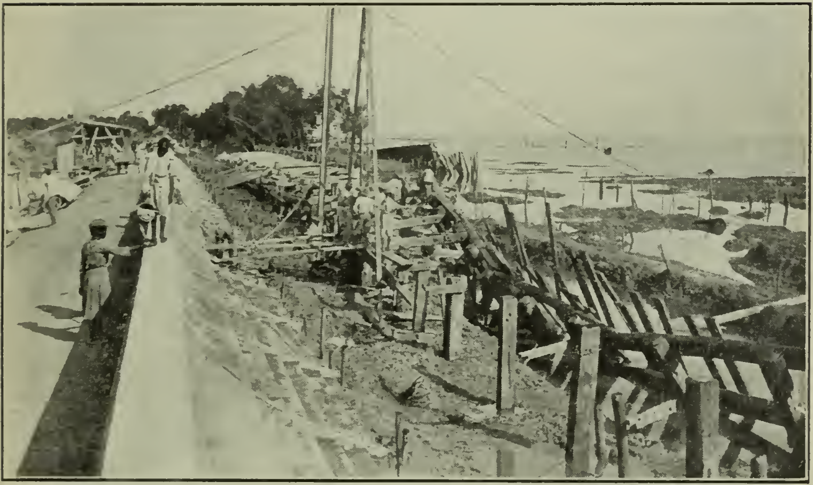


FIG. 11. REINFORCED CONCRETE SEA WALL AND TWO BROKEN LINES OF TIMBER DEFENCES.

The recommendations made by the author were for the protection of over 50 miles of the coastline of British Guiana. The estimated cost of the works was $4,476,558. The works were commenced in 1916 and are now nearly completed. Since 1919 the work on the east and west coasts has been carried out by the Sea Defence Department, under the able direction of the Hon. J. P. Auld, M.I.C.E.

The following table shows approximately the amount of work involved :—

	Lin. Feet.
Sea Wall	26,000
Reinforced Concrete facing to earth dam	23.000
Earth dams	25,000
Road diversions	29,000
And 115 Groynes.	

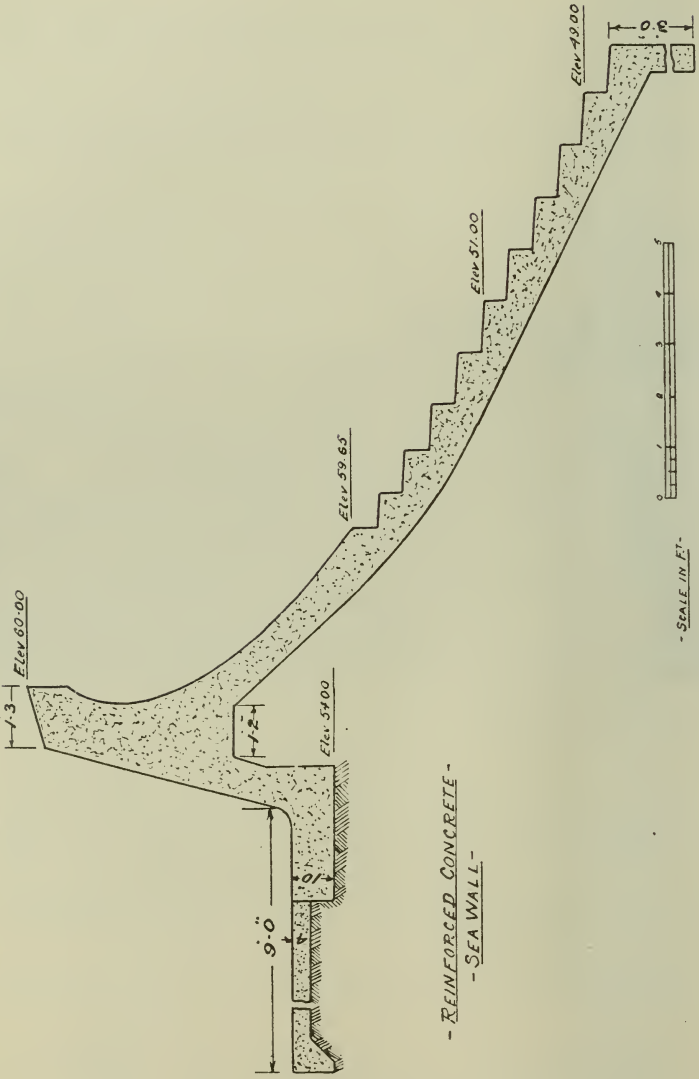


FIG. 12. REINFORCED CONCRETE SEA WALL.

In addition to the execution of the permanent scheme, a large amount of work had to be done in dismantling and removing old sea defences—stone and timber wave-screens, vertical sheet piling, etc.—which were causing erosion of the foreshore. By the end of 1919 about 1,500,000 cub. ft. of stone alone had been removed from wave-screens on the foreshore.

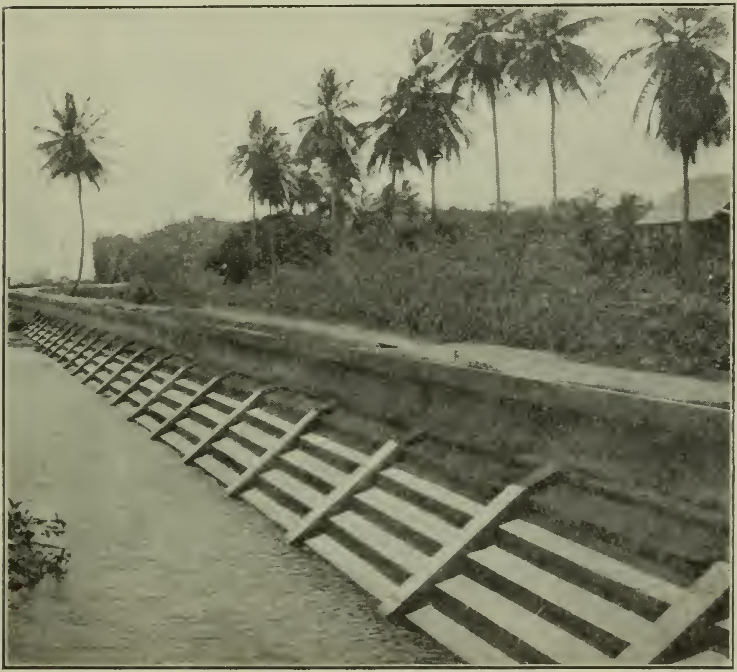


FIG. 13. REINFORCED CONCRETE FACING TO EARTH DAM.

In the first place, the groynes on the east coast were built 750 ft. long, and 1,500 ft. apart ; but it has been found necessary in some cases to build intermediate groynes.

As was to be expected in a scheme of this magnitude, some modifications have been found necessary from time to time. In the first place, the author considered it advisable to build training walls on each side of the drainage outlet ; but experience has shown that in some places one wall built on the leeward side is sufficient to prevent the drainage water flowing diagonally across and damaging the foreshore.

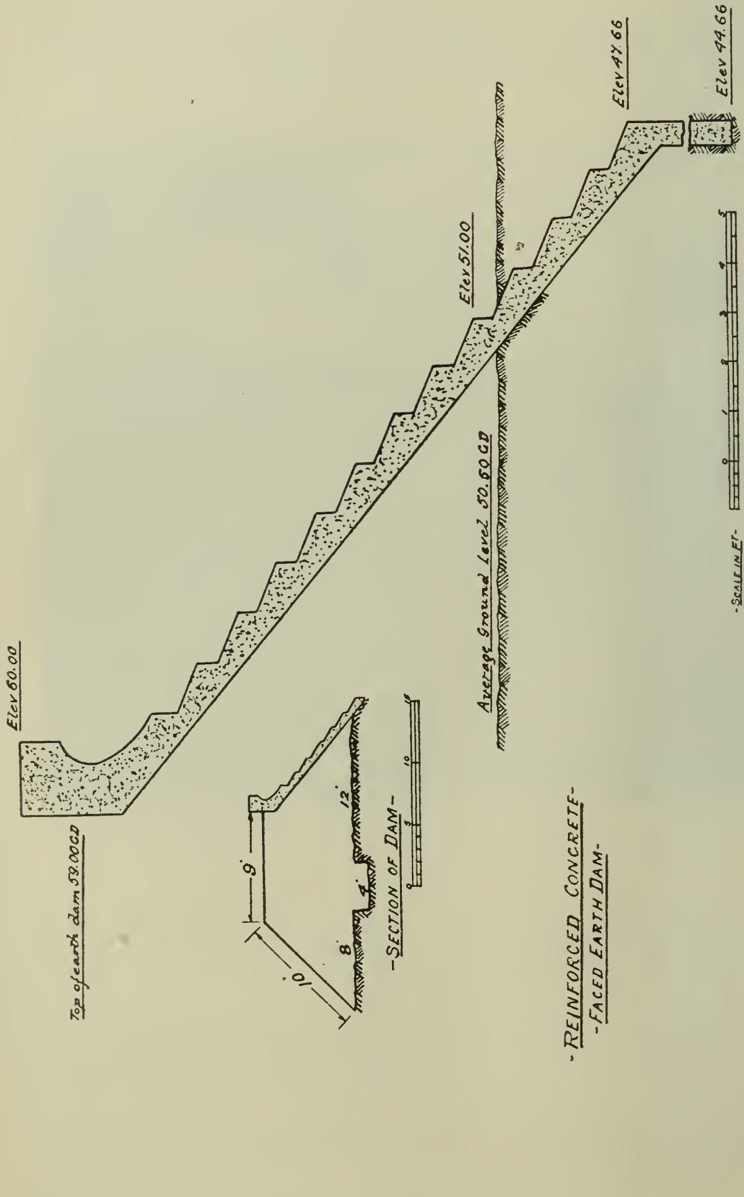


Fig. 14. Reinforced Concrete Faced Earth Dam.

On the Clonbrook, Lusignan and other sections of the coast, the groynes have built up the foreshore at a rapid rate. In front of the new Lusignan sea-wall the foreshore has built up an average of 3 ft. 6 in., and to a vertical height of 5 to 6 ft., in what were formerly the most eroded portions; while in some parts of the Clonbrook section, where in the spring of 1917 rapid erosion was taking place, and where part of the public road was washed away, and the balance threatened with entire destruction, we now find the foreshore built up to a height of 2 to 3 ft. above the roadway. In May, 1919, the author reported to the Officer Administering the Government that "the beneficial result has far exceeded what I anticipated when making my reports on the east and west coast of Demerara, and I know of no foreshore in England or elsewhere where groynes have so rapidly accumulated material as they have done on the east and west coast. Between Kitty and Plaisance on the east coast of Demerara the existence on the foreshore of stone wave-screens and other remains of the former sea defence work has, to a large extent, prevented the groynes rapidly building up the foreshore, but in all places where such screens and other structures had been entirely removed the groynes already constructed have done remarkably good work in building up the foreshore."

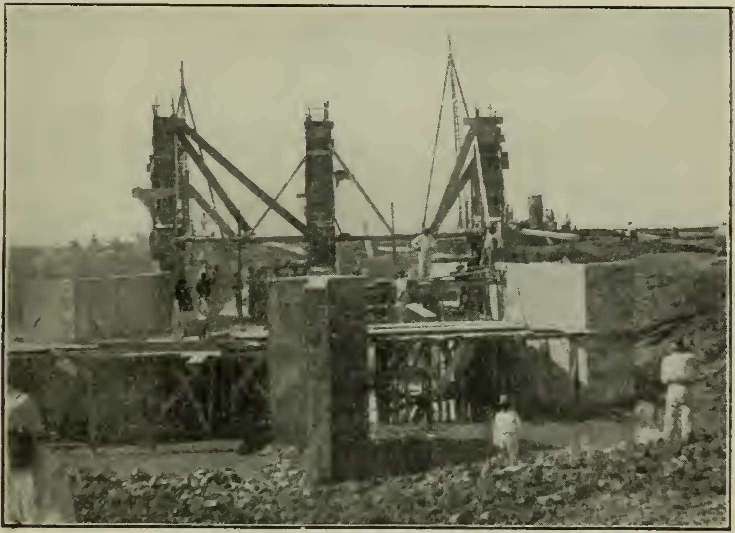


FIG. 15. REINFORCED CONCRETE DOUBLE SLUICE IN COURSE OF CONSTRUCTION (BACK VIEW).

Some difficulty has been experienced in keeping the groynes in a water-tight condition and preventing their being undermined and collapsing in places where there were old structures, such as wave-screens, in existence when the new groynes were first put in. The wave-screens, etc., caused scouring to take place, and prevented the new groynes from building up the foreshore. The obstructions were removed as rapidly as possible and the groynes strengthened where necessary. Experience on the British Guiana coast has shown that it is practically useless to put in a new system of groynes until all the old obstructions have been entirely removed.

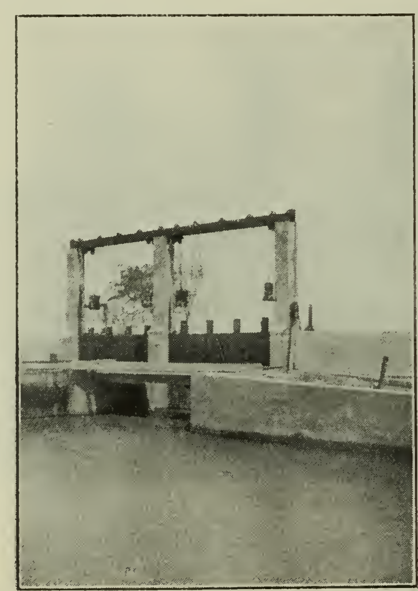


Fig. 16. Front View, Completed Double Sluice.

British Guiana is a country of almost boundless possibility. A large part of the Colony is entirely undeveloped, although possessing large areas of land suitable for growing sugar and other tropical produce, large cattle savannahs, vast areas of valuable forest, many valuable minerals, and in the Kaietur fall (which is only one of the many falls) possesses a source of power greater than that of Niagara.

To develop the resources of this rich part of the British Empire there is urgent need of a greater population. Although the health conditions have been greatly improved in the last 40 years, and

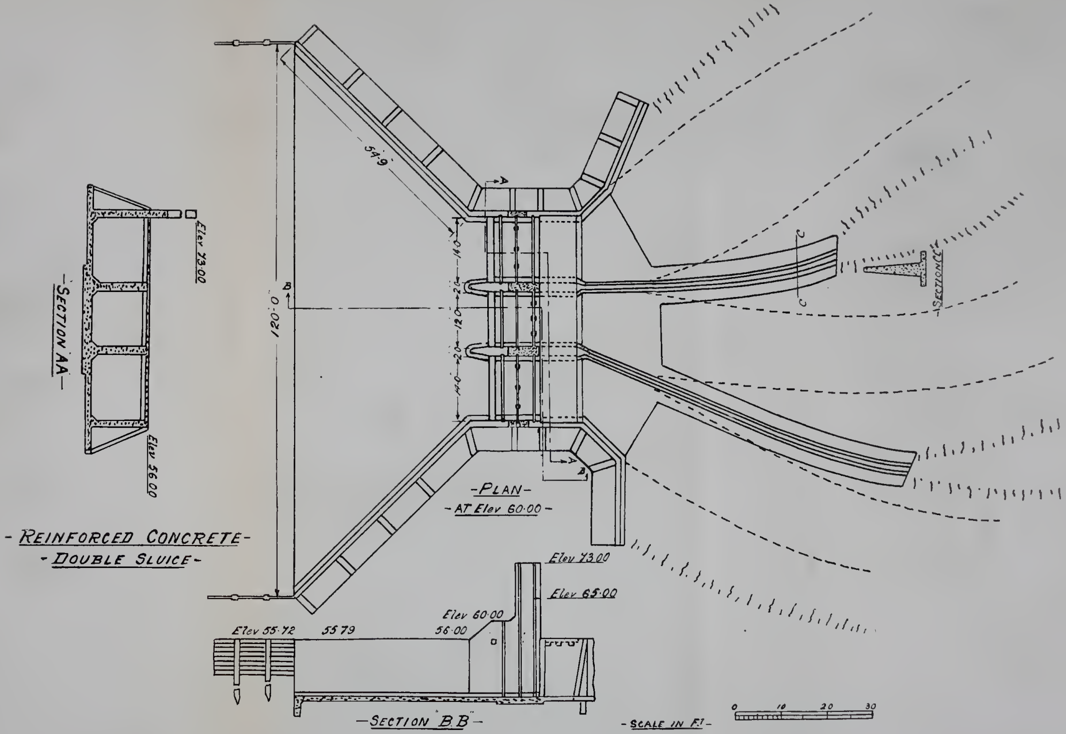


Fig. 17. Reinforced Concrete Double Sluice.

yellow fever, plague and cholera have been entirely stamped out, there is still room for great improvement, as the Hon. C. Clementi, Colonial Secretary of British Guiana, recently stated, "Although, however, the development of the Colony imperatively demands the introduction of emigrants in considerable numbers, it is evident that the most pressing duty of the Government is to protect the lives of the existing population."

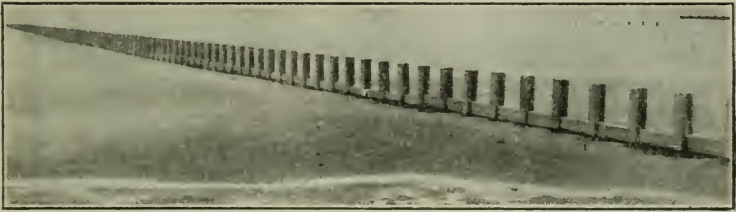


FIG. 18. REINFORCED CONCRETE GROYNE.

The construction of the scheme of permanent coast protection work has a most important bearing on the health of the Colony, as it will enable the low-lands to be properly drained, at an annual cost which, in the author's opinion, should little exceed the the cost of the present inadequate system of drainage. In the past, owing to the constant necessity of retiring the line of sea dams inland as erosion took place, the sugar estates and villages, for economical reasons, were forced to place their drainage engines some distance inland from the line of sea dams. The practice being to drain by gravity wherever possible, and during heavy rains to pump the water on to the front lands at the back of the sea dam. As these front lands are in many cases populated by West Indian and East Indian labourers, and their families, it has been impossible to stamp out malaria and other tropical diseases, and the death rate has been consequently high.

After studying the drainage of the reclaimed land in Europe, the United States, and other countries, the author is of opinion that now that the coast protection works have been made of a permanent nature, it should be possible to drain the reclaimed lands of British Guiana at a comparatively small cost, thereby making the Colony as healthy as any other tropical country.

The author is of opinion that the following work is necessary to drain properly the reclaimed land :—

(1) The construction of a reservoir canal on the land-side of and close to the sea-wall or sea dam. The earth obtained in excavating the canal to be thrown up on the land-side to form an inner dam.

(2) The construction of sluices controlling the discharge of water from each sugar estate and village into the reservoir canal.

(3) The installing of suitable pumping plant at the various reinforced concrete sluices built in line with the sea-wall or sea dam so that during rain storms water can be pumped over the sea-wall into the sluice run at any state of the tide.

It is suggested that the reservoir canal, outer sluices and pumping plant be under the control of Drainage Commissioners appointed by the Government and landowners, and that their business would be either to take advantage of natural drainage through the sluices, or to pump when necessary to keep the water level down, so that the sugar estates and villages could always drain through their own sluices into the reservoir canal. This would enable the owners of sugar estates to control the water level of their own land, independent of their neighbours or of the villages. It would be the duty of each estate and village to keep their interior drains to their own sluice dug sufficiently deep to drain the land efficiently, power being given to the Commissioners to enforce this being done.

The author is of opinion that the effect of the groynes in building and maintaining a high foreshore for coast protection purposes will make it impossible always efficiently to drain the land by gravity only during heavy rainstorms, and that although the greater part of the water can be got rid of through the sluices, the installation of pumping plants to pump water direct into the sluice runs is essential. During dry weather banks of mud are sure to come in and fill the sluice run. It is highly probable that after pumping for a short time the run would be cleared of the mud and then gravity drainage could be resorted to. At the present time each estate and village on the east coast has its own pumping plant, and some estates several plants.

The author is of opinion that if the scheme as outlined by him is carried out, the annual cost of maintenance and sinking fund on capital expenditure in constructing the reservoir canal and pumping plants would be little more than the present cost of pumping on to and flooding the inhabited areas. The location of a pumping plant on the line of the sea wall or sea dam would enable the water to be pumped direct into the sluice run, with a result that any mud accumulated in the run during dry weather would be rapidly dispersed, thus enabling gravity draining to be resorted to much quicker than it is now, and consequently reducing the cost of pumping. At the present time it is often necessary for the sugar estates to send out large gangs of men at low tide to clear with shovels the sluice run which has become silted up with mud during the dry weather.

DISCUSSION.

Lord Headley, B.A., M.I.C.E., I., F.S.E., expressed the pleasure he felt in presiding on the occasion of Mr. Case's paper. Foreshore work had been his hobby for a great many years, and he owed a great deal of his knowledge to his old friend the late Mr. Edward Case, the lecturer's father. The principle of low groyning was a correct one, and had been put into practice with good results at many places. He had been called in to advise about the preservation of a portion of the coast line near Singapore where extensive cocoa groves were in danger of being washed away by the sea. The owners were about to expend many thousands of pounds on the construction of a sea wall of stone to be carried by ship from long distances. He had pointed out to the owners that the soft and muddy nature of the alluvial deposit was most unfavourable for the construction of heavy masonry work which would be rapidly lost in the untrustworthy foundations, and that the extensive piling necessary to insure the stability of the wall would be prohibitive in cost. He had then furnished plans for the construction of the simplest low groynes formed of interlaced bamboos and other suitable material, and the cost of the whole system was only about £500. The great thing aimed at by the low groyning was encouraging the deposit of travelling silt and, as it were, humouring the sea instead of opposing it by main force. The sea, ever whimsical in its action, required a vast amount of understanding before it could be turned into an efficient builder up of any shore. Once hit off the correct kind of device and place that device in the correct position, and it might be possible to convert the destructive agencies into constructive agencies, thus securing the services of untiring and unceasing waves and currents for the building up of a natural foreshore.

The following communication was read :—

From **Prof. E. R. Matthews, A.M.I.C.E., F.R.S.E.**

In the author's advice to the Government of British Guiana, Item No. 7 is particularly interesting, for it relates to the removal of all existing structures which were causing erosion. Unfortunately this wise procedure is not always adopted, but new works are put down and the old are allowed to remain on the foreshore, thus causing a good deal of scour. It is amazing when visiting coast towns to find all sorts of obstructions left upon the shore. On several occasions when the writer has been called upon for advice by local authorities *re* a sea defence scheme, he has suggested that before any new work is commenced, the remains of previous sea walls, and other sea defence structures, should be blown up or otherwise removed.

Last week the writer made an inspection of a fairly recently built sea wall. The structure was good, but the toe of the wall had been undermined for almost the whole length of the wall ($\frac{1}{4}$ mile), and this was due entirely to piles, which had been left in, 3 ft. or more in front of the wall, at intervals of about 10 ft. Certain sheet piling had also been allowed to remain in front of the wall, and this and other obstructions had caused a scour along the full length of the wall, the foundation thus being undermined.

In another case it was found that certain piles had been allowed to remain on the shore, and the scour around these had caused a permanent deep pool of 20 or 30 ft. in diameter on the foreshore. It is sometimes a mistake even to leave large rocks on the shore, as these frequently cause scour.

In the writer's opinion, the Author of this paper acted wisely in using reinforced concrete for his sea-wall and groynes, and the profile of the wall is a useful one. Long low groynes are undoubtedly the best that could have been used on that particular shore. The reinforced concrete face to the dam, illustrated in Fig. 14, is not, in the writer's opinion, heavy enough to stand the pummelling action of the sea. These remarks also apply to the sea wall illustrated in Fig. 12.

Mr. Havelock Case, M.Inst.C.E., said the subject dealt with was becoming more and more recognised as of great importance from a national point of view; he would therefore like to congratulate Mr. Gerald Case on his having had the good fortune to deal with such interesting work in a new country which presumably is free from all, or most, of the difficulties, such as vested interests, with which Engineers are confronted in older and more settled countries like England.

The speaker had some knowledge of several of the West Indian Colonies, Panama, and Columbia, but had no idea that British Guiana had so large an area below tide level and such a vast extent of marsh lands subject to flooding. The author's paper spoke of the evil effect of man's interference with natural conditions, but the speaker took it from what followed that the interference more especially meant was the local, non-co-ordinated and frequently conflicting works of independent proprietors. We were all agreed as to the extreme importance of concerted and co-ordinated control of all works of coast defences and reclamation drainage operations. An illustration nearest at hand was the Dagenham Breach on the North bank of the Thames which occurred in the year 1707, and the evil effects of which might be seen to-day, and which was only put right by the State after private interests had struggled for years to deal with the trouble and failed. Mention was made of erosion taking place on the leeward of drainage outfalls, and that such outfalls always tend to follow the line of littoral drift, that was the line of least resistance. A very good illustration of this effect might be seen at Christchurch, where the combined discharge of the rivers Avon and Stour turns in an easterly direction flowing nearly parallel with the shore line and occasionally breaks through the diverting shoals thrown up in front. The result being that valuable residential property facing the Needles was jeopardized. The speaker recently advised as to protective works for private property owners in the absence of any controlling and responsible authority at this place.

He was glad to hear the remarks on the evil effects of permitting the indiscriminate removal of shell, or in fact any kind of littoral drift, from the coast line. For he was at present concerned in a case where proprietary rights were claimed and shell was being removed to the prejudice of the security of most valuable tidal lands which had been reclaimed and cultivated for some hundreds of years.

There were many new forms of protective facing. His experiences prompted him to say that he had found the old and tried dry rubble pitching the most satisfactory. He did not like any homogeneous and continuous skin of concrete for the reason that subsidence in the earthwork mass of these walls was continuously taking place, and whereas dry rubble pitching should always settle with the earthwork on which it was supported and thus be easily seen and attended to when necessary, this was not the case with a concrete skin which held up and bridged over such settlements and hid them from view until they became dangerous. He realised that there might be special reasons which applied to British Guiana and which would amply justify the use of concrete as advocated by the author. With this one exception he endorsed the ten items of work scheduled at pp. 188-9.

The author's difficulties due to setting of the sluice outfalls he much sympathised with, as he had found it to be a constant source of trouble with the many sluice outfalls under his charge on the river Thames. During dry weather periods, when discharge was small or possibly ceases, these outfalls tended to silt up rapidly, so that when the floods came and rapid discharge was necessary, trouble ensued. The most serious instance, on account of its magnitude, which he had been concerned with was the large outfall of the middle level in the Fens. The sluices of this outfall are nearly 800 yds. from the tidal waters of the river Ouse, thus forming an outfall channel subject to the deposit of silt for many feet in depth and well above the cills of the sluices. Owing to the state of the channel in 1916, the Commissioners were compelled to carry out extensive dredging operations; 100,500 cu. yds. of silt was removed by dredging and the Commissioners' Engineer found by soundings taken in March of the year 1918 that 70,000 cu. yds. had been redeposited since the dredging operations of 1916.

If the author could be induced to supplement his most interesting paper with some detailed figures of the costs of his works in relation to the area of land reclaimed, and the proportional lengths of sea walls and protective works to the area of land which such works protect and drain, it would be greatly appreciated and considerably add to the already great interest of his paper.

Major F. J. Gray, O.B.E., A.M.Inst.C.E., said the subject had been dealt with in that able and illuminating manner which marked the papers read by the author on previous occasions before the Society of Engineers.

The subject had a special interest for the speaker, because the author, his brother, and he, were associated twenty-one years ago in reporting on the protection of the shores of Demerara and Essequibo. The wave action and the velocity of the tidal currents on that coast normally are very slight, but at times they acquire a force sufficient to move large areas of the sling mud and to denude the shore in places. When and where this action occurred, the sea dams used to be liable to be breached and the back lands to be flooded.

Knowing the difficulties attending the construction of works across and along this unstable shore, and the complex nature of the engineering problem to be solved, the author was to be congratulated on his right judgment in designing suitable structures, and on the successful results which he had attained.

It was a matter of satisfaction to the speaker to find evidence that the principles of design which guided him twenty years ago, guide the author to-day. It was true that reinforced concrete was not used in those days for sea defence works but the speaker designed sea-walls to the same kind of elliptical profile as that shown in Fig. 12; he planned drained outlets between pairs of groynes of the same kind as that to which the author alluded, and his groynes had the same kind of longitudinal elevation as that shown in Fig. 18. Moreover, the author appeared to be in agreement with the speaker as regards the basic principles underlying sea defence problems. Firstly, there was the demarcation of the natural line of breakers, consonent with the depth of water seaward, the range of the tides, and the direction and force of the prevailing winds. This indicated the distance seaward to which lands, hitherto subject to flooding by the sea, could be reclaimed without running counter to the natural forces at work on the shore. Secondly, on shores subject to rapid erosion, sea walls and similar defences were in no-wise an all-sufficient means of protection. The really effective factor of protection on such shores was the building up of the full and foreshore, to a safe height and to a natural inclination of repose ; and this could be done only by the passive resistance offered by low groynes to the currents running along or obliquely to the coast-line, and by the effect thus produced on littoral drift.

The statement at the bottom of p. 184 appears to suggest that the detritus brought down by the rivers of British Guiana was inappreciable in amount and consequently of no effect on the shore. If the speaker could rely on his recollection, the shore of the Golden Fleece sugar plantation, and other shores dissected by rivers, consist of material coarser than caddy sand. Such material is undoubtedly derived from the detritus brought down by rivers, for it is identical with that found on their banks.

As regards paragraph 8 of p. 189, the speaker desired to know what method the author recommended for encouraging the growth of vegetation in front of the dams. Some details of the species and planting would be instructive. The speaker agreed that vegetation should be encouraged to grow on certain shores in front of dams. He remembered that on the shore of Golden Fleece, where the sea did not encroach, the full was planted with sedge grass, to prevent the sand from being blown away, and even to help to preserve a natural barrier to the wash of the breakers.

Mr. Hal Gutteridge, A.M.I.Mech.E., Memb.Tech.Insp.Assoc., said : I have been an interested listener to Mr. Case's particularly lucid account of the land reclamation of the tidal marshes in British Guiana, where he had to design a coast defence scheme that would resist the peculiarly difficult conditions that exist in that part of the world ; these difficulties he had grappled with, the result of which he had told us.

The speaker had recently read an account of a somewhat similar scheme carried out in the municipality of Delta, British Columbia, by H. M. Burwell, M.E.I.C., where they had the same difficulty of the sluice gates not providing the necessary discharge at low tides to secure sufficient drainage during the wet season, which Mr. Case has mentioned with his recommendation of installing suitable pumping plant to overcome this. In the Delta scheme they erected pumps on the sluice gates which had justified their installation, and proved effective in handling this problem. An interesting mechanical feature of the pumping set was the provision of vertical radial vanes, fore and aft, on the outside of the suction pipe, to obstruct the whirlpool action of the water round the pipe.

In Australia, near the mouth of the river Yarra at Melbourne, there were problems of land reclamation which had had to be overcome, such as dealing with siltage, shifting mud banks, low lying inundated ground, etc., with the result that there was now, owing to its close proximity to the city of Melbourne, much valuable reclaimed ground that had been won and turned to good use.

It would be of interest if Mr. Case would give some details of the proportions of aggregate, sand and cement that had been used in the construction of the sea-walls, and concrete faced earth dams, and the considerations that led to the adoption of the stepped face to the walls.

Mr. T. J. Gueritte, B.Sc.(Paris), M.Soc.Ing.Civ.(France), Vice-President, said, having had the privilege some 10 years ago to be connected with an important scheme of coast protection carried out by the author in this country, he was pleased to see him back after having occupied so well the few years he spent in British Guiana.

A few months ago, in course of the discussion of a paper on the sea defences at Blackpool, read before this Society, he had mentioned that low groynes, gradually built up, were in his opinion preferable to high standing ones. He was interested to find that such an authority on this subject as the author asserted once more, after his extensive American experience, that such was the case.

He fully agreed with the author's view regarding the danger frequently presented by vertical sheet piling defence, whether a single row were provided or whether there were two rows enclosing stone filling. The scour shown by Fig. 9 was unfortunately too common, and his firm were replacing an old wall of which this very photo would be a faithful representation.

He noticed that the author had taken care to provide a series of steps, both horizontal and vertical, the former to retard the downward flow of water when the wave receded, and thus avoid the danger of scour at the toe of the wall. This feature was uncommon in such walls in this country, but would no doubt prevent the scour. If the waves carried, as was usual, a large quantity of pebbles, there would be the danger of a fairly rapid abrasion of the steps, unless very hard aggregate were used for the concrete of the steps. Perhaps the author would give some information on this particular point.

The speaker noticed that the walls were of a considerable length. In such a country the range of temperature might be great, and the effects of expansion and contraction might be marked. It would be interesting to learn what provisions, if any, had been made to guard against trouble from this cause.

Mr. C. H. J. Clayton, M.Inst.C.E. (Member), in referring to the subject of the sillation of tidal outfall channels mentioned in the paper, instanced the case of the Middle Level where the sluices which discharge the water of the main drain into the river Ouse are placed at a considerable distance back from the river. It had been found that the intervening channel operated seriously as a trap for the collection of river silt, and that freshes coming down through the sluices were not effective as a means of removal. He understood that the Middle Level Commissioners had spent considerable sums in dredging operations, but that no permanent remedy had yet been found. He had little doubt that the long drought of the present year had caused serious deterioration in this and similar channels, and that some of the shoals which had been formed would by this time have become too hard and compact to be removable by winter flood waters.

As regards the question of the ferro-concrete facing of earthen dams, he was bound to say that he agreed with the observations of his friend, Mr. A. Havelock Case. So far as the soil of reclaimable lands along our own coasts was concerned, a degree of settlement which might be taken roughly at ten per cent. of the height of the dam certainly did take place, and that, even after such consolidation, further movements due to the drainage of the lands behind the dam, alterations of temperature, humidity and so forth, were to be looked for. Apart from these, there was honeycombing due to the depredations of moles, rats, and rabbits, and he thought that all or any of these causes of instability might make it risky to rely upon the appearance of an unbroken ferro-concrete skin as evidence of the condition of the underlying mass of the dam.

Nothing had been said by the author about the cost of the work. It was to be presumed that chiefly native labour had been employed and that costs would be correspondingly low. A recent experience of his own in connection with the reclamation of about 330 acres of outmarsh on the Wash had convinced him that the acquisition of ordinary agricultural land by reclamation or sea-defence works at current rates for labour was absolutely prohibitive.

Mr. A. E. Carey, M.Inst.C.E., wrote saying he considered Mr. Case's paper a useful addition to the literature of land reclamation, but that the information was rather of a sporadic character, and it would have made the situation clearer to those not knowing the coast line, if a diagrammatic sketch or bird's eye view of the frontages comprised in Mr. Case's operations had been furnished.

The estimated cost of the work was roughly £900,000, or about £18,000 per mile of frontage dealt with. It would be interesting to know what the actual costs per lineal unit of the various works set out at p. 189 were. The reinforced concrete veneer or facing to the earth dams, as carried out according to sections (Figs. 12 & 14), must have been costly to construct.

Generally Mr. Case appeared to have adhered closely to the methods of the De Muralt system of coast protection.

It is obvious that the construction of a reservoir canal on the land side of the coast works, on the lines of Dutch practice, is an inevitable sequel to the operations already carried through, as, without such canal, the drainage and control of land waters would be unattainable.

The rainfall of British Guiana must be extreme, and the effects of the impounding of land waters, unless control is secured, either by gravitation or pumping, will be disastrous. It must result in a condition of things deleterious to health and damaging to the stability of the lands in the rear of the sea defences.

The adoption of the expedient of plant winning of the lands of British Guiana is referred to by Mr. Case in a somewhat sketchy manner. In *Tidal Lands*, by Carey and Oliver, p. 183, the methods employed by Mr. J. Junor on the Demerara River are given in detail. Mr. Junor planted *Spartina brasiliensis* in rows 6 ft. apart, the plants being 2 ft. apart. When this grass had become firmly established, Mr. Junor planted seedlings of the mangrove between the ranks. One peculiarity of this plant (*Rhizophora*) is that its seeds germinate while still attached to the parent stock. Mr. Junor states that the result of his efforts in arresting disturbance of the foreshore by means of this planting was notable. The matter is more fully referred to by Mr. A. W. Bartlett in the *Journal of the Board of Agriculture* of British Guiana, Vol. I., No. 3, January, 1908.

Considering how amazingly prolific vegetation is on tidal tropical marsh lands, it would appear that planting on an extended scale should produce marked results in reclamation and maintenance. The writer had a vivid recollection of the rampant halophytic growth on the tidal saltings of Trinidad.

Mr. Ernest Latham, M.Inst.C.E., A.M.I.Mech.E., wrote saying, there is no doubt that the author had contributed valuable information on the subject of coast protection and maintenance, especially as applied to low lying lands.

It would be of interest if the author could give the composition and sieve analysis of the sand in the two tabular statements at p. 184. The composition appears important, as the silica content is separated in the tables.

In regard to the movements of the mud banks immediately off the coast line, marine surveys of a somewhat extensive character and examination of scouring velocities, etc., appear necessary, and if the author has any definite data obtained by the Colonial Government it would undoubtedly be of value to maritime engineers. Apparently the mud of which these banks is composed possesses similar properties to the alluvium of the Yellow River Delta in China, referred to in some detail by Mr. J. R. Freeman, of the American Society of Engineers, at the Engineering Conference held this year at the Institution of Civil Engineers. The percentage of matter in permanent suspension at varying velocities is an important factor.

The author in his paper clearly demonstrates the well known difficulty of maintaining at the same time efficient coast protection works and efficient land drainage, especially in the case of rapid accretion on a foreshore due to the construction of groynes. The author's cure for restoring obstructed drainage by the establishment of a reservoir canal and pumping stations appears to be a rational but necessarily expensive solution. In view of the recent findings of the French Government Commission on the use of tidal power, and their first concession in respect of the estuary of the river Rance in Brittany, it would be of interest to know whether the proposed reservoir canal system could be so adapted as to comply with the requirements of " balanced reservoirs " automatically providing the necessary source of power for pumping. The author unfortunately does not give the range of tide, though from the photographs this would appear not to be great.

In advising recently on a proposed tidal hydro-electric scheme, with land lying below high water level, it appeared to the writer to be practicable to maintain *continuous* power. This undertaking may never be carried out owing to the fact that the power available is limited and the range of tide low, two factors which are not favourable to the necessary heavy expenditure.

In the case of British Guiana, the cost of establishing a reservoir canal will in any case be involved, and, if the system could be adapted to supply power automatically for pumping at high water and during exceptional land floods, the proposal might be worthy of consideration.

REPLY.

The author in replying to the discussion thanked the members for the reception accorded to his paper. He stated that he was much interested in Lord Headley's description of the

Singapore coast protection work, and congratulated his Lordship on the results of the work, which was an interesting example of the utilization of the forces of nature to build up at a small cost a defence against the destructive forces of the sea.

The author fully agreed with Prof. Matthew's view of the importance of removing all old obstructions before attempting to carry out a comprehensive system of coast protection works. Referring to Prof. Matthew's opinion that the wall shown in Figs. 12 and 14 was not heavy enough to withstand the pummelling action of the sea, the author stated that a good deal of the work was carried out in 1916, and that although there had been a number of severe storms since then, no important damage had been done by direct sea action on the concrete facing. Owing to the action of the groynes in building up the shore the severity of the wave action was becoming less as the sand and silt were accumulated in front of the wall.

The author stated that he had considered the use of stone pitching to face the dams in British Guiana, and after careful consideration had advised the use of reinforced concrete both on the grounds of efficiency and economy. Both Mr. Havelock Case and Mr. Clayton appeared to be under a misapprehension with regard to the construction of the concrete facing to the earth dams. The earth dams were built as far as possible in advance of the concrete work in order to allow settlement to take place. The concrete was not built on the dams in one continuous skin, but was built in panels as shown in Fig. 13, the space between the panels being afterwards filled in with concrete forming the beams which are clearly shown in the illustration.

Mr. Havelock Case's experience of the silting of the outfall channel of the middle level of the Fens seems to substantiate the author's conclusion stated at p. 196 with reference to the silting up of outfall channels. With reference to Mr. Havelock Case's question about the cost of the work in relation to the area of land properly drained, the area of the east coast district is approximately 55,000 acres, and the cost of protecting this district was about two million seven hundred and sixty-four dollars.

The author said he fully agreed with Mr. Gray as to the necessity of constructing groynes in places where rapid erosion was taking place. With regard to the statement at p. 184 of the paper that the rivers flowing to the coast of British Guiana bring down practically no material in suspension, the author agreed with Mr. Gray that a considerable amount of material on the Essequibo coast was brought down by the river, but in his opinion this material, which was chiefly sand, was moved along the bottom by current action and not to any large extent brought down by suspension.

Experiments have been made by the Department of Science and Agriculture to obtain information concerning the best species of vegetation to plant on the British Guiana coast, but no definite conclusions have yet been arrived at. In some sheltered places good results have been obtained by planting courida (*Arcennia nitida*) and black mangrove (*Rhizaphora mangle*), and in slightly more exposed places spartina grass was growing well.

In reply to Mr. Gutteridge's question, the author stated that the concrete was generally made of three parts broken granite, two parts sand, and one part cement, but where necessary these proportions were varied so as to insure a dense concrete.

The object of the steps to the face of the sea walls was to check the velocity of the back wash.

Referring to the question of abrasion of the steps raised by Mr. Gueritte, the author stated that in British Guiana the littoral drift was composed entirely of fine sand and mud, and that no difficulty had consequently arisen. In building the sea wall, expansion joints were used about 50 ft. apart ; in the concrete dam facing no expansion joints were required to the main part of the facing, as it was built in independent sections, the spaces between the sections being afterwards filled in with concrete beams.

In reply to Messrs. Ernest Latham and A.E. Carey's written communications, the author stated that in his opinion it would be impracticable to use the proposed reservoir canal as a source of power for pumping, as there is little water to discharge except during the heavy rainstorms, when the water would rapidly fill up the reservoir canal.

Referring to the unit cost of the various works, the author stated that owing to the greater part of the work being carried out under war conditions the cost varied greatly for the same type of work owing to wide variation in the cost of cement, steel, etc. The final average costs of the various types of work were not yet available.

Monday, 7th November, 1921.

THE RIGHT HON. LORD HEADLEY, PRESIDENT,
IN THE CHAIR.

EXTRACTION TURBINES.*

By C. H. NAYLOR, A.M.I.C.E.
(*Of the British Thomson-Houston, Co., Ltd.*)

It is not to be supposed that the extraction turbine by any means supersedes the ordinary turbine ; it is merely a special type of turbine which has been designed to meet definite circumstances.

The expansion of steam, the explosion of coal gas, oil vapour, and so forth, as a means of transforming heat into mechanical energy is, after all, inefficient. Indeed, in the case of steam, with the best type of turbines, the best practice, the very highest steam pressures and highest superheat, it is not possible to get more than 26% of the whole of the heat energy converted into electrical energy, or, say, 27% of the whole heat energy transformed into mechanical energy. This margin of inefficiency, so to speak, gives the opportunity for the introduction of all kinds of devices for the purpose of obtaining better economy when special circumstances permit. The extraction turbine has been designed to meet the conditions in manufacturing processes where heating steam is required at the same time as power. In such circumstances an opportunity of obtaining power at a very cheap rate occurs ; the reason being that the major portion of the loss in the ordinary turbine is due to heat being carried by the steam into the exhaust pipe or into the condenser, as the case may be. If the rejected heat, after leaving the turbine, can be used for some other purpose, say, in the manufacturing process of a factory, greater economy can be obtained. The extraction turbine has been designed for this purpose.

Neither mechanical nor electrical energy can be obtained from heat without losing that heat equivalent and therefore it is not to be supposed that, if steam is passed through a turbine, that a certain amount of energy is to be obtained without loss in the heat value of the steam. Of the heat which is converted into mechanical energy in the extraction turbine, 92%, or it may be even more, is realised as mechanical work and heat which would otherwise be lost goes into the factory in the heating steam. This method gives a very distinct advantage.

The extraction turbine treated as a subject alone would not form, in itself, sufficient matter for a complete paper ; in fact, it would not be understood if treated by itself. In these circumstances it is necessary to explain the theory of turbines in general before introducing the subject of the extraction turbine.

---

* Read before the Wolverhampton and District Engineering Society (Associated with the Society of Engineers) on January 16th, 1920.

In the early days the pressure and volume of steam were of first consideration and little attention was given to the actual temperature of the steam or its heat contents. This remark, however, requires a certain amount of qualification. Generally speaking, the area of an indicator diagram, if read properly, represents foot-pounds of work and this value when divided by 778 gives the heat equivalent in B.T.U. ; so that, if a diagram of steam pressure and volume which has performed work on a piston is measured and the area of that diagram be taken to represent foot-pounds and be divided by 778, the result will give the number of heat units. The steam must have lost that number of heat units because it has done that external work. Seeing, therefore, it is a question of heat units it is much more convenient to work these problems from the point of view of the heat that is being converted into mechanical work, and it is necessary to have a heat diagram for reference.

The Theta Phi diagram, refers to one pound of steam or one pound of liquid,—water, in this case. The diagram is drawn to represent the total heat contents of water and steam up to any pressure or any temperature. The method of drawing the diagram is briefly as follows :—The water line is started from 32°F., which is taken as a datum point and a vertical line extending from 32°F. down to Zero temperature on the absolute scale. If another line is drawn to the right of the line described above, the area enclosed must represent heat. The vertical height represents the temperature, but the originators of this diagram found it difficult to imagine what the co-ordinate of temperature would be and so the word " Entropy " was invented for this quantity. Temperature multiplied by entropy gives an area and this area represents heat units.

It is assumed that heat is added to the water, and that the diagram represents an area, it is the whole of this area under the water line that represents heat in the water.

Considering a pressure of say 100 lb. per sq. in., it is known that the temperature corresponding to that pressure, which is indicated on the vertical scale, cannot be increased without evaporation of the water. Any more heat put into the water would, unless the pressure were increased, fail to raise the temperature and therefore the temperature would remain constant. Thus, in order to enclose an area, the entropy must be increased until a point is obtained when the whole of the one pound of water has been evaporated. After that point the temperature will rise and superheat begin with another series of lines in the superheat region. The diagram represents the total heat contents of a pound of steam at any pressure and temperature desired, within the limits stated. and the heat available is that portion which lies above the vacuum line.

The term "thermo-dynamic efficiency" means the proportion of the available area which has been converted into mechanical or electrical work. Thermo-dynamic efficiency is with reference to the small area within the working limits; thermal efficiency is in reference to the whole of the area of the chart. If gas or oil engines are being compared with steam engines, naturally it is necessary to speak in terms of thermal-efficiency; that is, the whole efficiency. If comparing the efficiencies of various steam plants then thermo-dynamic efficiency is generally referred to. The thermo-dynamic efficiency is of chief interest to designers, because the conditions of vacuum, superheat and pressure are available and the plant is designed to obtain the greatest efficiency from these conditions. The buyer, however, should be most concerned about the thermal efficiency because he has to pay for the heat in coal. In fact, in most turbines that are built the more the vacuum is increased, the lower the thermo-dynamic efficiency obtained, and yet the thermal efficiency is improved in these circumstances.

THERMO-DYNAMIC AND THERMAL EFFICIENCY.

Steam Conditions.

275 lb. per sq. in. gauge pressure, 300° F. superheat, 29 in. vaccum.
Heat contents at pressure and superheat ... ... = 1368·3 B.Th.U.
Heat contents at 29 in. vacuum after adiabatic expansion ... ... = 901 ,,
467·3 ,,
Steam consumption of a 12,500 K.W. Turbo-Alternator running at 1,500 r.p.m. ... ... say 10lb. per K.W.Hr.

Thermal Efficiency. (Boiler efficiency, 100%).

Heat supplied to steam assuming the boiler feed is 79° F. (which is the temperature corresponding to 29 in. vacuum) .... = 1,368·3+32 — 79 = 1,321·3

Thermal efficiency .... $\dfrac{3,420}{1,321\cdot3 \times 10} = 25\cdot9\%$

Thermo-Dynamic Efficiency......... $\dfrac{3,420}{467\cdot3 \times 10} = 73\cdot2\%$

The above shows the calculations for both thermo-dynamic and thermal efficiency, and extreme conditions have been taken with the object of obtaining the best results possible. A turbine, working with pressures as high as 350 lb. per sq. in., and a temperature of 700° F., has been built. Referring to the above calculation, the total heat contents, at the pressure and superheat, by reference to the Theta Phi diagram, or by reference to steam tables, is seen to be 1,368·3 B.Th.U. The heat contents of steam at the pressure corresponding with a 29 in. vacuum after an adiabatic expansion is 901, and this amount cannot be reclaimed with the exception of the heat remaining in the condensed steam. The difference of 467·3 B.Th.U. is the amount that can be made use of.

With regard to the turbine, it would appear a doubtful proceeding from the point of view of efficiency to allow steam to expand freely through a nozzle. When steam is allowed to expand through a nozzle, pressure energy is lost and becomes velocity energy. After velocity energy has been obtained it would seem a doubtful proceeding to try to recover that velocity energy by allowing the steam to impinge on a revolving bucket ; and yet, for large powers, say, at any rate, above 400 h.p., it has been proved to be the most efficient way of dealing with the expansion of steam.

Steam Nozzle Data.

If steam is allowed to expand through a nozzle, the nozzle throat pressure is only 0·58 of the initial pressure, and no matter what pressure is prevailing at the exit of the nozzle it is impossible to obtain any lower pressure at the throat of the nozzle than 0·58 of the original pressure. However, expansion of the steam does continue afterwards until the steam is reduced finally to a pressure P3, but velocity may have been given to the steam in all sorts of directions and eddies. If a divergent nozzle is placed on the end of the nozzle throat, all the eddies that have taken place after the nozzle throat may be conserved, and use can be made of the whole of the pressure drop.

After the velocity of the steam, as it issues from the nozzles of the steam turbine, has been determined, it is necessary to decide how the energy may be transferred to the revolving bucket on the wheel of the turbine. The whole of the efficiency can be worked out by this diagram in every case, although it is rarely resorted to in practice.

Arrangement of Nozzles and Blades.

This illustration shows the method employed for compounding for velocity. By putting a certain amount of divergence on the nozzle, it is possible to get the whole of the heat drop converted into velocity, and afterwards, having converted it fully into velocity, the velocity may be reduced by the revolving buckets until the final velocity is as small as possible. This method was the first which suggested itself, but it has been abandoned, as it has been found impossible to pass steam through more than three rows of buckets in this manner without eddies forming, and confusion resulting instead of a proper stream line. That method is called "compounding for velocity." It is never resorted to where high efficiency is required.

SECTION OF TURBINE (Two Buckets per Stage).

This illustration shows the method employed in compounding for pressure. Instead of converting the whole of the heat energy into velocity, the heat energy is divided into four portions, and a turbine of this design is called a four-stage turbine. Each stage, however, is compounded for velocity in so much as there are two rows of revolving buckets per stage.

SECTION OF BLADES (One and Two Rows).

The illustration shows a section of nozzles and buckets; on the left are two rows of buckets and one still bucket in between. On the right is shown the most efficient method—one row of buckets and one nozzle; and by this method the total heat drop is divided between a larger number of stages, only one row of buckets being used each time the steamis expanded and that fraction of heat being used in each stage.

In the design of turbine which employs single rows of buckets, on all except the first stage, many wheels are employed, but it is more efficient to compound for pressure than it is to compound for velocity. This statement requires qualification, however, because rotation losses and size have a modifying effect.

FIG. 1.—CURVES OF BUCKET EFFICIENCY.

Instead of working out the efficiency of a combination of nozzles and revolving buckets in every case, curves are available which, to a certain extent, give a general efficiency. If the bucket velocity and the steam velocity are both known, it is possible to establish a certain ratio which is called "the velocity ratio." Bucket velocity can very rarely be more than 800 ft. per second; steam velocities can be as much as 4,000 ft. per second. The steam velocity is obtained by deciding the heat drop per stage, and then from the heat drop the velocity is calculated, and by reference to the heat diagram or steam tables the steam pressure can be found. Higher maximum efficiency can be obtained for one row than for two rows of buckets. Present day practice is distinctly in the direction of one row of buckets per wheel.

STEAM CONSUMPTION ESTIMATE.

After calculating the bucket *water* rate, it is necessary to estimate the power lost after the buckets have received it. The wheels revolving in the steam absorb a considerable amount of power. There is friction of the bearings, the oil pump, and

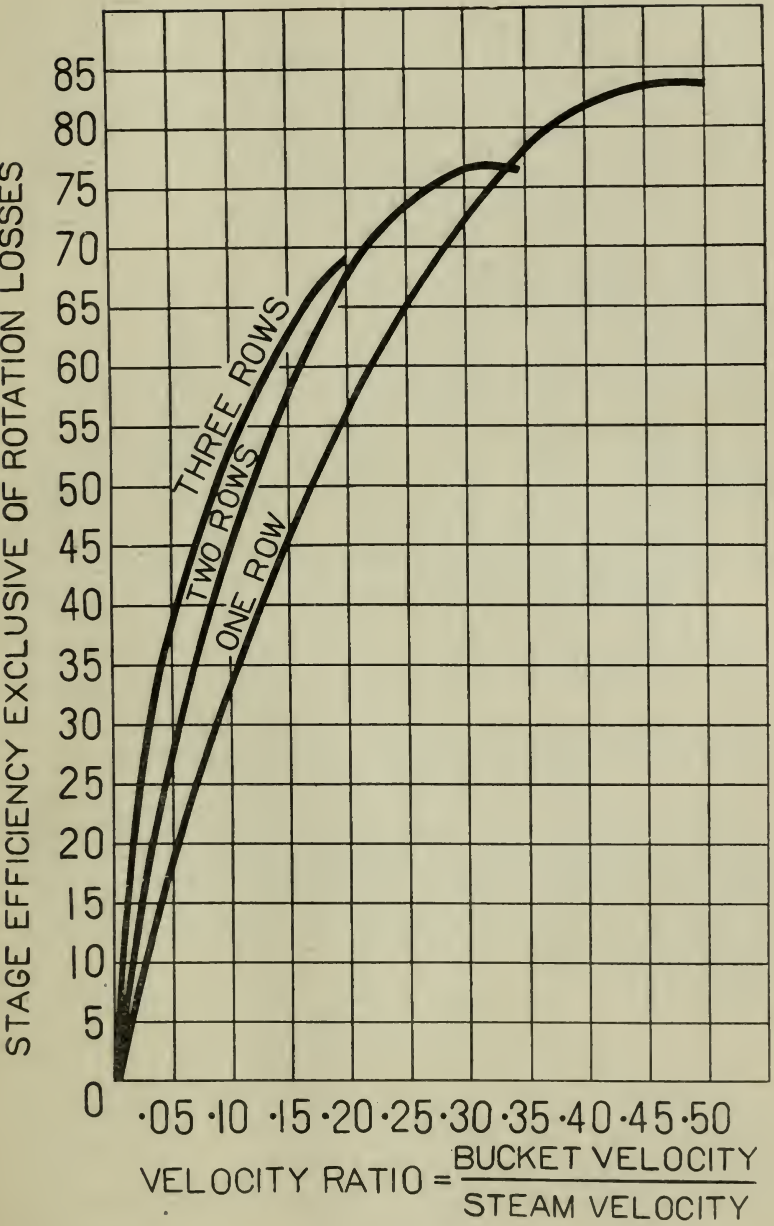

STAGE EFFICIENCY EXCLUSIVE OF ROTATION LOSSES
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
·05
·10
·15
·20
·25
·30
·35
·40
·45
·50
THREE ROWS
TWO ROWS
ONE ROW
VELOCITY RATIO = BUCKET VELOCITY / STEAM VELOCITY

FIG. 1.

the governor gear. There is leakage of steam estimated as power. The total amount of power lost can be obtained by the addition of such values, and the total steam consumption over all will be the load plus the losses, multiplied by the bucket *water* rate. Thus the overall water rate is affected by these losses. That method is generally adopted for estimating the steam consumption, and is illustrated by the following example :

$$V_1 = \left\{ \begin{array}{l} \text{The velocity of the steam} \\ \text{as it leaves the nozzle} \end{array} \right\} = 223 \cdot 8 \sqrt{\text{heat drop.}}$$

$$\frac{b}{v} = \frac{\text{bucket velocity}}{\text{steam velocity}} = r = \text{ratio}$$

From curves find η, the efficiency corresponding to r.

$$E_B = \left\{ \begin{array}{c} \text{heat converted into power} \\ \text{at the bucket} \end{array} \right\} = \eta \text{ heat drop.}$$

$$\left. \begin{array}{l} \text{Steam consumption per} \\ \text{B.H.P. at bucket} \end{array} \right\} = \frac{2545}{E_B} = \text{bucket water rate.}$$

LOSSES—	B.H.P.
Rotation of wheels in the steam	—
Friction of bearings and the driving of oil pump and governor gear	—
Leakage of steam estimated as power	—
Total	—

$$\text{Total steam consumption} = (\text{load} + \text{losses}) \times \left\{ \begin{array}{l} \text{bucket} \\ \text{water rate} \end{array} \right\}$$

THERMO-DYNAMIC POWER DATA.

At first sight it would appear that, independent of the size of the turbine, the number of stages in a turbine would depend upon the total heat drop. A small turbine, however, will have a few stages, and large turbines require a large number of stages, because of the influence of rotation losses. The following illustrates the procedure :—

Wheel = 61 in. dia. Speed = 3,000 R.P.M. Bucket speed = 800 ft. per sec.

Rotation loss = 3,000 × steam density.

In all stages, except the first, the heat drop is arranged to be 55·5 B.Th.U., which gives 89% stage efficiency exclusive of rotation losses. The first stage efficiency is that resulting from the utilisation of the remaining heat drop.

Total thermo-dynamic power × bucket efficiency = rotation losses + rating.

The quantities in the following table have been calculated for steam conditions of 180 lb. per sq. in. by gauge, 150° F. superheat, and $28\frac{1}{2}$ in. vacuum.

Heat drop 380·2 B.Th.U. S, the specific volume, = 357·2 cu. ft. per lb.

Rating B.H.P.	THERMO-DYNAMIC POWER. Supplied in the form of heat energy. B.T.U.						
	1 Wheel.	2 Wheels.	3 Wheels.	4 Wheels.	5 Wheels.	6 Wheels.	7 Wheels.
250	483	*468*	492	600	846	1,300	2,040
500	1,092	884	*858*	933	1,155	1,590	2,330
1,000	1,885	1,720	*1,600*	1,600	1,778	2,170	2,890
1,500	2,820	2,550	2,340	*2,270*	2,400	2,760	3,450
2,000	3,750	3,390	3,080	*2,930*	3,020	3,340	4,020
3,000	5,610	5,050	4,550	*4,270*	4,270	4,500	5,140
4,000	7,480	6,725	6,030	5,590	*5,520*	5,670	6,250
6,000	11,220	10,051	8,970	8,270	8,000	*7,980*	8,510
10,000	18,700	16,750	14,850	13,600	13,000	*12,650*	13,000

NOTE.—The values *in italics* shew the best number of stages for that diameter of wheel, speed, and power.

Take Rating at 250 B.H.P.

One wheel. V = 4,365 ft. per sec. $r = 0 \cdot 1835$. $\eta = 0 \cdot 535$.

$$\text{Rotation loss } \frac{3{,}000}{357 \cdot 3} = 8 \cdot 42 \text{ B.H.P.}$$

$$\text{Thermo-dynamic power} = \frac{258 \cdot 42}{0 \cdot 535} = 483 \text{ B.H.P.}$$

Two wheels—

2nd wheel $\eta = 0 \cdot 89$. $r = 0 \cdot 48$. V = 1,665.

Heat drop = 55·5 B.Th.U.

1st stage press = 2·16 lb. sq. in. abs. S. = 135·8 cu. ft. per lb.

1st wheel H = 325. V = 4,030. $r = 0 \cdot 198$. $\eta = 0 \cdot 55$.

$$\text{Combined efficiency} = \frac{55 \cdot 5 \times 0 \cdot 89 + 325 \times 0 \cdot 55}{380 \cdot 2} = 0 \cdot 6$$

Rotation losses, 2nd wheel = 8·42 B.H.P.
" " 1st " 22·1 "
30·52 "

$$\text{Thermo-dynamic power} = \frac{280 \cdot 52}{0 \cdot 6} = 468 \text{ B.H.P.}$$

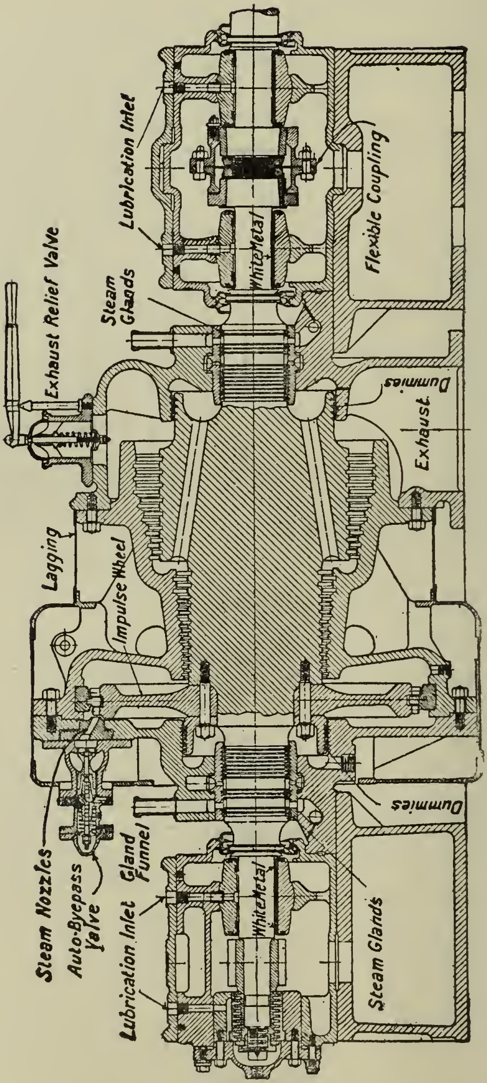

Exhaust Relief Valve
Steam Glands
Lubrication Inlet
White Metal
Flexible Coupling
Dummies
Exhaust
Lagging
Impulse Wheel
Steam Nozzles
Auto-Byepass Valve
Gland Funnel
Lubrication Inlet
White Metal
Dummies
Steam Glands

FIG. 2.

Three wheels—

2nd and 3rd wheels $\eta = 0\cdot89$. $H = 111$.

1st stage, pressure $= 5\cdot72$ lb. sq. in.abs. S, the specific volume, $= 56\cdot9$. cu. ft. per lb.

1st wheel $H = 269\cdot2$. $V = 3{,}670$. $r = 0\cdot218$. $\eta = 0\cdot59$.

$$\text{Combined efficiency} = \frac{111 \times 0\cdot89 + 269\cdot2 \times 0\cdot59}{380\cdot2} = 0\cdot678$$

Rotation losses, 2nd and 3rd wheels = 30·52 B.H.P.
,, ,, 1st wheel = 52·8 ,,
83·32 ,,

$$\text{Thermo-dynamic power} = \frac{333\cdot32}{0\cdot678} = 492 \text{ B.H.P.}$$

FIG. 2.—SECTION OF REACTION TURBINE.

This illustration shows Parsons' first reaction turbine. By replacing the wheels by a drum rotation losses are reduced, but other difficulties are involved in end-thrust and steam leakages. The leakage of steam takes place past the balance pistons and over the tops of the blades in the original Parsons' turbine. Due to the large number of blades, it was not found to be a mechanical device that would stand up against practical usage.

RELATIVE THERMAL EFFICIENCIES.

This being calculated for a 1,000 KW. turbine, and assuming that the whole of the steam passes to the heating system, then whatever heat is lost under these conditions, 92·25% of it is converted into mechanical work. This is the reason of the extraction turbine's efficiency. The efficiency in the use of the steam which passed to the condenser is no better ; in fact, it is worse than if it had passed through a high-pressure turbine, but the amount which goes to the condenser must be arranged to be the smaller amount. A similar 1,000 KW. high-pressure turbine compares as follows :—The total heat is 1,278 B.Th.U., and the thermal efficiency is 20%. It is, therefore, worth installing an extraction turbine where conditions permit, and the quantity of heating steam is sufficient to warrant its being adopted.

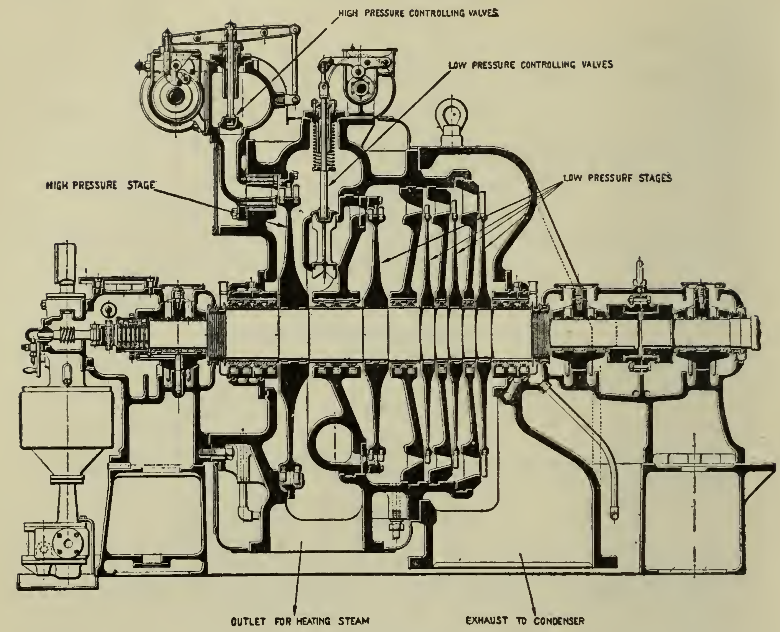


Fig. 3.

Extraction Turbine Duty.

To make the extraction turbine a useful device, it should be possible to vary the power required from the turbine without it affecting the quantity of heating steam. A second condition necessary is to give a supply of heating steam at constant pressure, and any volume up to the full output designed ; it must be possible to meet a variation in the quantity of heating steam if necessary, because the quantity of heating steam depends upon the demands from the factory, and the turbine must fulfil these conditions. If it is not possible to supply more steam than the maximum load will allow to pass, and if the load is not available, steam cannot be passed through. An additional quantity of heating steam can be obtained, however, by making use of a by-pass reducing valve. A by-pass pipe is taken from the main inlet to the heating steam pipe, and contains an ordinary reducing valve, so that should the demand for heating steam be greater than the turbine will give (that is to say, when the whole of the heating steam is passing through to heating, and none of it is going through to the condenser), then, if more steam is required what will really happen will be that the pressure will drop slightly in the heating pipe. The reducing valve in the by-pass from the steam inlet will automatically open and give the extra supply required.

EXTRACTION TURBINE SECTION.

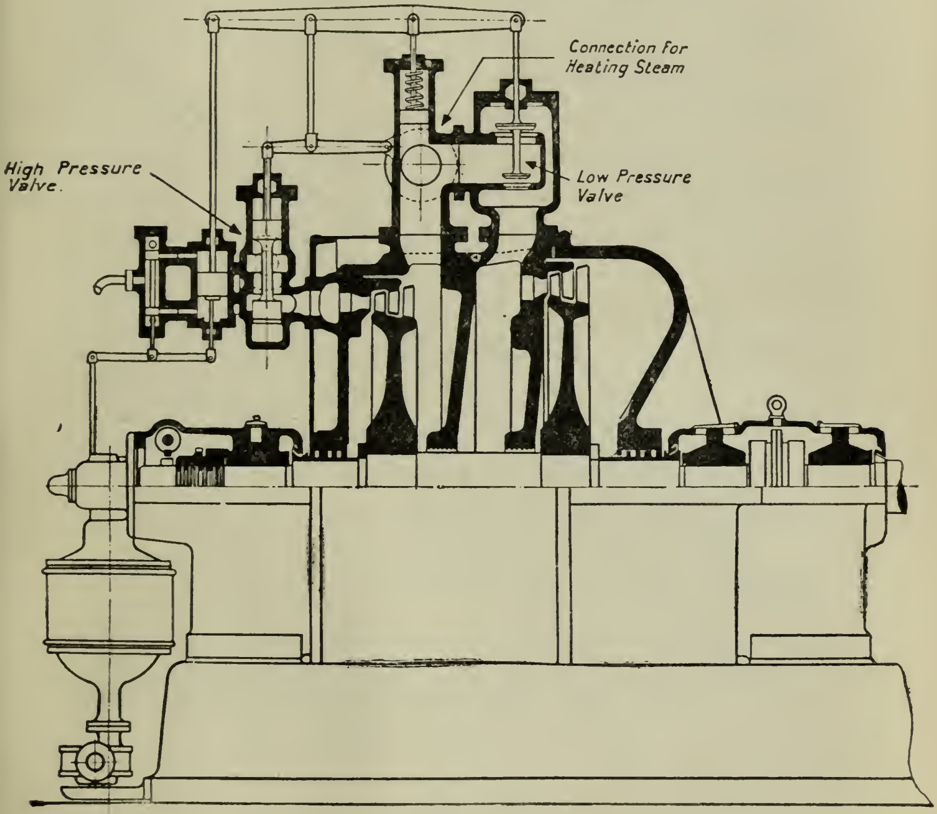


FIG. 4.

FIG. 5.—STEAM CURVES FOR EXTRACTION TURBINES.

Where the power required is great, say 4/5,000 KW., and the quantity of heating steam required is only sufficient to give half load, it is better to supply two turbines—one a back-pressure turbine for heating purposes, and the other a high-pressure turbine coupled electrically to the former. This can be done, and the two together make one extraction turbine. An advantage is gained in this method in that the high-pressure turbine is better economically than an extraction turbine, used simply as a high-pressure turbine.

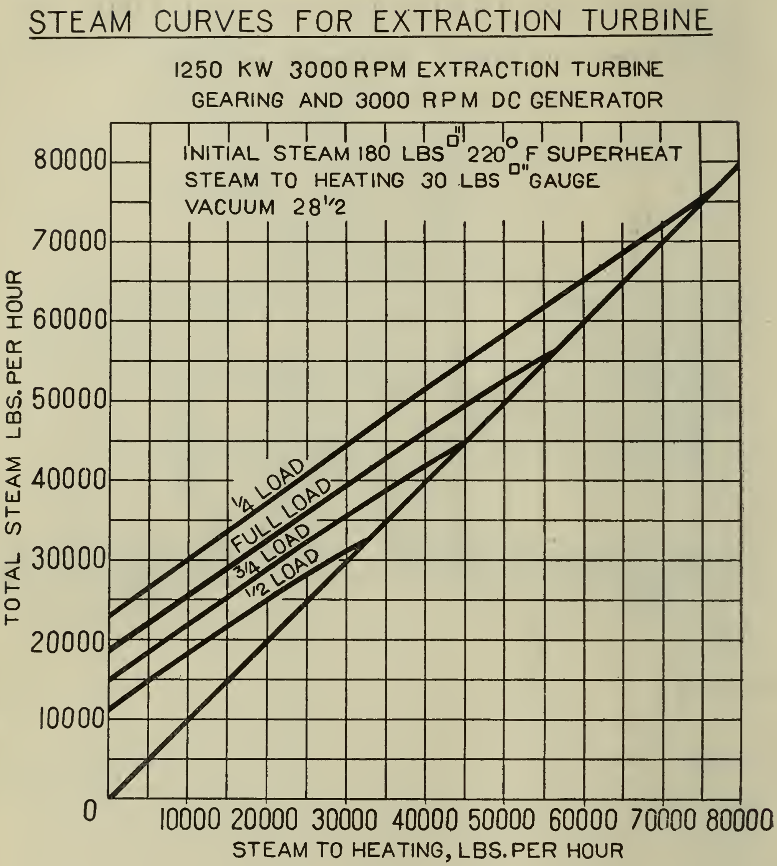


Fig. 5.

Discussion.

Mr. W. H. Patchell, M.I.C.E., M.I.M.E., M.I.E.E., said :—

Mr. President, ladies and gentlemen, the author's excellent lantern lecture has been much more interesting and instructive than the paper as printed. You, sir, spoke in your opening remarks of by-products. That question was receiving much attention, but what was the by-product was not always agreed! The speaker heard last week in Manchester of a mill where the owners were persuaded to change to electric driving in place of driving by steam power. The subsequent bill for electricity was a large one, while their coal bill was very little less than previously as so much steam was required for heating and process work.

The lecture on Entropy reminded him that while some professor said there was no such thing, it was, at any rate, a more or less efficient way of expressing our misuse of steam.

The blanks on the author's table included one for gland losses. In connection with big machines this particular loss was giving much anxiety.

The development of the turbine, as shown on the slides, finishing up with the Parson's type, was an amusing instance of living backwards! At any rate, the author justified the survival of evidence of the type in other designs.

The governor gear, shown for extraction turbines, was somewhat akin to that used on mixed pressure turbines, where low pressure steam was brought into the turbine for further expansion and used as power instead of being discharged to atmosphere, as in colliery winding engines.

" Extraction " or " bleeding " was no new thing, either from reciprocating engines or turbines, but it was the improvement in governors and such details which rendered it of greater utility with safety in operation.

Would the author tell us whether the bucket speed of 800 ft. per sec. referred to 1,500, or 3,000 r.p.m. machines ?

Mr. H. G. Brotchie, A.M.S.E., said he considered the extraction turbine an ideal unit in a factory where steam was required as well as motor power, but he did not agree with such turbines being coupled to an alternator with another turbo-alternator of the ordinary type. This he considered might appear possible from a hypothetical point of view, but from a mechanical one, owing to the possible variation of demand for steam by the factory the governing of the turbine would be erratic because of the fact that four throttle valves operated to govern the speed of the turbine. These throttle valves had a nasty habit of sticking, and even with a variation of 2½ per cent. (Mr. Naylor's figure) this would be enough to set up hunting on the alternators and possibly cause one to be tripped on reverse when lightly loaded.

Mr. C. T. Walrond, F.S.E., A.M.I.C.E., A.M.I.E.E., asked at what pressure steam for heating was usually taken from extraction turbines and whether in designing such turbines it was convenient that steam should be extracted at one pressure rather than another.

Mr. C. H. Naylor, A.M.Inst.C.E., in reply to Mr. Patchell's remarks, thanked him for the way in which he amplified the paper.

Entropy was a difficult thing to conceive, but it served its purpose as an imaginary quantity.

The author did not think that gland losses should be a serious item in a well designed machine of the impulse type where the gland diameters were as small as the diameter of the shaft itself.

With regard to the description of the reaction turbine backwards from the impulse turbine, there was one essential difference which the author omitted to mention. It was assumed that the fixed rows of buckets in the reaction turbine were equivalent to the diaphragms and nozzles of the impulse turbine. In the reaction turbine the nozzles were really the revolving blades or partially the revolving blades, and partially the fixed blades, that is to say, there was a gradual pressure drop between the inlet and outlet of any set of blades, whether revolving or fixed—hence the end thrust on the rotor as a whole.

The author pointed out that the governor was designed not only to take care of the change of load, but also of the change of heating value of the steam, so that when the extraction turbine was working in parallel with another turbine, coupled on the electrical side, it would be able to take its proper share of the load at all times, no matter what the variation of the heating steam supply might be.

The bucket speed of 800 feet per second referred to in the paper was feasible for either 1,500 r.p.m. or 3,000 r.p.m. machines.

Replying to Mr. Brotchie's remarks, the author stated that extraction turbines designed with the special type of governor gear which he had described, worked perfectly well in parallel with other turbo-alternators, and endeavoured to show by diagram how this was arranged for. When there was a diminution in the requirements of heating steam the governor gear not only by-passed a certain amount of this heating steam through the remaining stages of the turbine to the condenser, but also cut off the main supply to the turbine from the high pressure main in such a manner that the extraction turbine took its proper share of load when working in parallel with another set. He pointed out that such a gear need not be absolutely precise in bringing about a perfect sharing of the load, but it should be sufficiently near the mark to safeguard the extraction turbine from being unduly overloaded, or from throwing too great a load on the other set. The gear, as described, was working satisfactorily in service at the present time. If, as suggested by Mr. Brotchie, a throttle valve were to stick, this would be only what might happen with any other type of turbine working in parallel and would not be a failure attributable to extraction turbines in particular.

In reply to Mr. Walrond, the author stated that 30 lb. per sq. in. gauge pressure was favoured as suitable for the heating steam supply. Working with lower pressures than this, although favourable to economy as far as the turbine was concerned, did not give much pressure margin for process purposes after distribution losses through the factory had occured ; working with higher pressures of heating steam detracted from the economy gained by the turbine.

Monday, 5th December, 1921.

THE RT. HON. LORD HEADLEY, PRESIDENT,
IN THE CHAIR.

NORTHWICH SEWERAGE AND SEWAGE DISPOSAL WORKS.

By WILLIAM MARROW BECKETT, M.B.E., Assoc.M.Inst.C.E., M.S.E.

Northwich is situated in mid Cheshire on the well-known salt-producing area and suffers heavily from subsidence caused by the abstraction of brine. The extent of the subsidence may be judged from the fact that the solid salt removed each year is equivalent to about 1 ft. in thickness over an area of 1 sq. mile.

Salt Beds.—There are two main beds or deposits of salt under the town, each about 90 ft. thick, separated by a bed of marl some 30 ft. in thickness. The salt has been removed partly by mining and partly by pumping brine. In the top bed many acres of salt were obtained by dry rock mining, pillars of salt being left in the mines to support the superincumbent strata. Subsequently water found its way into these old mines; they became flooded and are now simply underground reservoirs whence the brine is pumped to the surface. Similar mines have been worked in the lower rock salt bed, and one or two are still worked, but the others have all been flooded. Rainwater percolating through the ground finds its way down to the upper surface of the first salt bed and passes thence to the old flooded mines and other pumping stations, dissolving and collecting the salt during its passage until it becomes fully saturated. This occurs when the water has taken up about 26 per cent. of its own weight of salt. When fully saturated the brine flows on to the pumps without removing any more salt and consequently without doing further damage. The brine in its passage to the pumps follows lines of least resistance. As the salt is dissolved the ground above sinks down and fills up the cavities and thus the brine runs are often diverted into new channels.

The water or brine flowing into the old mines, if not already fully saturated, gradually dissolves the salt pillars with the result that the roofs collapse and huge cavities appear at the surface and extensive "flashes" and deep pools of water have been formed in this manner. The combined areas of the flashes which have been thus formed on the North side of the town exceed 120 acres, and some of them are over 80 ft. deep.

The area of subsidence is more or less clearly defined on the surface and, from observations taken by the Author over a period of about 30 years, it appears that, while within the area the points affected are frequently changing and the rate of sinking varies considerably from time to time, the southern boundary of the sinking area has not appreciably extended except in one or two isolated cases.

On the accompanying Drawing (Fig. 1), the boundary of the Urban District is shewn and also the boundary of the subsiding area. The Southern boundary of the subsiding area follows an irregular line a little to the South of Witton Street, which is the principal street leading from the railway station to the centre of the town.

The rate of sinking in the lower portion of the town is so serious that it has been found necessary to raise certain lengths of the main street 5 or 6 ft. at intervals of about 10 years. Practically all the buildings are made on the framed principle and are periodically lifted bodily off their foundations by means of hydraulic and screw jacks and then underpinned with brick work and concrete.

Private owners receive some compensation from the brine pumpers for the damage done to their buildings, under an Act of Parliament entitled the Brine Pumping (Compensation for Subsidence) Act, 1881, but no compensation is paid for damage done to the streets, sewers, water and gas pipes, and the heavy expense of raising and repairing the streets and relaying the sewers and water pipes has to be provided for out of the district rate.

Population.—The Urban District of Northwich embraces an area of 1,398 acres, and has a present population of about 20,000.

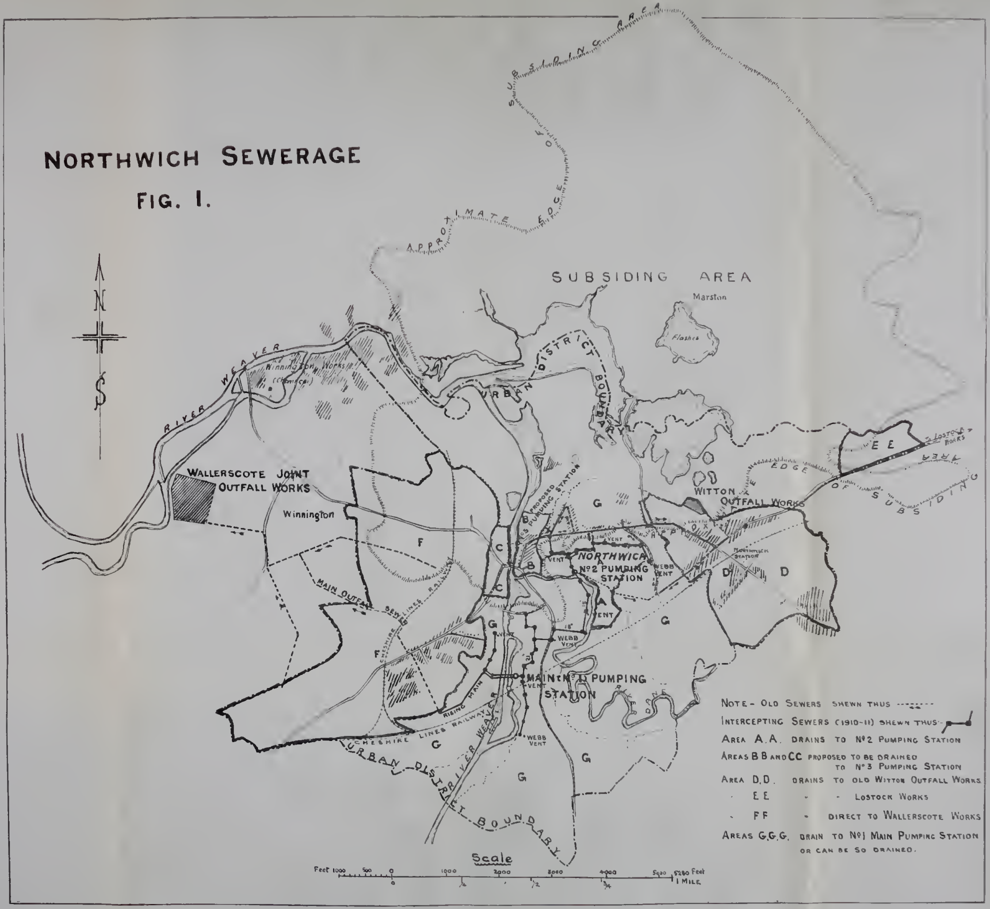
In 1891 the population was 14,914
,, 1901 ,, ,, ,, 17,611
and ,, 1911 ,, ,, ,, 18,151

Old Sewers.—The North East portion of the district (lettered DD on Drawing Fig. 1, and embracing a population of about 4,500 persons), has an old system of sewers gravitating to the Witton Sewage Works. A small area in the extreme North East corner (lettered EE) with a population of about 400 persons, is drained by arrangement with the adjoining Rural District Council to their Lostock Gralam Outfall Works while the Western, portion (lettered FF) with a population of 4,500 has a system of sewers constructed about 22 years ago which gravitate to the Wallerscote Outfall Works. Up to the year 1911, when the works described in this paper were commenced, the remaining portion of the district embracing a population of 9,000 persons, discharged crude sewage through various outlets into the river Weaver and its tributary the river Dane.

New Works.—In 1909 the Urban Council accepted a scheme submitted by the Author for dealing with this portion of the

NORTHWICH SEWERAGE

FIG. 1.



N
S
SUBSIDING AREA
APPROXIMATE EDGE OF SUBSIDING AREA
Marston
Flashes
RIVER WEAVER
Winnington Works (Chemical)
URBAN DISTRICT BOUNDARY
WALLERSCOTE JOINT OUTFALL WORKS
Winnington
F
F
MAIN OUTFALL
CHESHIRE LINES RAILWAY
C
C
B
B
No 3 PROPOSED PUMPING STATION
G
VENT
NORTHWICH
A
No 2 PUMPING STATION
WEBB VENT
A
VENT
18"
WEBB VENT
MAIN or No 1 PUMPING STATION
VENT
RISING MAIN
RIVER WEAVER
RIVER DANE
WEBB VENT
G
G
G
G
G
WITTON
OUTFALL WORKS
NORTHWICH STATION
D
D
E E
To LOSTOCK WORKS
EDGE OF SUBSIDING AREA
URBAN DISTRICT BOUNDARY
NOTE - OLD SEWERS SHEWN THUS
INTERCEPTING SEWERS (1910-11) SHEWN THUS
AREA A.A. DRAINS TO No 2 PUMPING STATION
AREAS B B AND CC PROPOSED TO BE DRAINED TO No 3 PUMPING STATION
AREA D.D. DRAINS TO OLD WITTON OUTFALL WORKS
" E E " " LOSTOCK WORKS
" F F " DIRECT TO WALLERSCOTE WORKS
AREAS G.G.G. DRAIN TO No 1 MAIN PUMPING STATION OR CAN BE SO DRAINED.
Scale
Feet 1000 500 0 1000 2000 3000 4000 5000 5280 Feet
0 1/4 1/2 3/4 1 MILE

district. The scheme embraced a system of high level intercepting sewers, laid in the non-subsiding portion of the district, picking up the existing sewers and delivering the sewage at a main (No. 1) pumping station situated on the East bank of the river Weaver and immediately North of the Cheshire Lines Railway Viaduct. It also included two auxiliary pumping stations (No. 2 and No. 3) for dealing with the low level areas which could not be directly drained to the high level intercepting sewer. The area draining to No. 2 pumping station (situated on the East side of the intercepting sewer) is lettered AA on the Drawing (Fig. 1.).

The areas proposed to be drained to No. 3 pumping station are lettered BB and CC on the Drawing.

The areas BB and CC have a combined population of about 1,500 and the scheme included a pump well and pumping station (No. 3) on the East side close to the river bank with a system of sewers gravitating thereto and a 9 in. steel syphon across the river for conveying the sewage from the west side to the pump well. From the pumps the sewage would be discharged through a 6 in. rising main to the top end of the intercepting sewer at the end of Leicester Street (point X on Map). The scheme was duly submitted to, and received the sanction of, the Local Government Board, but owing to the rapid subsidence going on in the areas BB and CC, the Board would not sanction a loan for the works included in this portion of the district, but advised that, when carried out, they should be paid for out of the rates. This portion of the scheme has consequently not been carried out, but the rest of the work has been completed as originally designed.

High Level Intercepting Sewers (Fig. 2).—The main intercepting sewer consists of 21 in. stoneware pipes from the main (No. 1) pumping station to Vearows Row, and thence of 18 in. and 15 in. pipes past No. 2 pumping station to its Easterly termination in Church Road. A little North of No. 2 pumping station a 12 in. branch passes in a North Westerly direction to the main in Witton Street at its junction with Leicester Street. At the bottom of Vearows Row a second 12 in. branch passes in a North Westerly direction and intercepts existing sewers in Hayhurst Street and Queen Street, while at a point a little East of the main pumping station another 12 in. branch passes in a Southerly direction and intercepts various old sewers from the Crescent district.

On the west side of the river Weaver a new 9 in. sewer, having a gradient of 1 in 200, has been laid along Navigation Road and across a shipbuilding yard to the towing path. From the towing path on the West to the pumping station on the

East side of the river a 9 in. steel syphon has been laid in the same trench as, and securely strapped to, the 12 in. rising main, which will be referred to later.

Immediately South of No. 2 pumping station the sewer is carried across the river Dane in 15 in. steel tubes supported on timber trestles in five spans of 27 ft. each (Fig. 3). Each trestle consists of two whole timber piles 24 to 30 ft. long driven into the bed of the river with a rake or batter outwards of 2 in. to the foot, with 12 in. by 6 in. side bracing and 12 in. by 12 in. cap piece to which the 15 in. tube is securely strapped. The lapwelded steel tubes have border ends and loose drilled flanges bolted together with 12-1 in. bolts to each joint. They are coated internally and externally with a special rust-preventing mixture and afterwards covered externally with two coats of tar. The pitch pine trestles are also heavily coated with tar.

The intercepting sewers are laid to the following ruling gradients, viz. :—

21 in. diam. 1 in 700.
18 in. ,, 1 in 600.
15 in. ,, 1 in 450.
12 in. ,, 1 in 300.

and when running half full all have a mean velocity of over 2½ ft. per second. In extreme dry weather the maximum daily rate of flow at any point will probably not exceed 2½ times the average dry weather flow from the population connected to the sewers above that point.

The following table shows the calculated depth of sewage flowing in the pipes and the velocity of flow in extreme dry weather :—

TABLE No. 1.

Situation.	Size and Gradient.	Max. D.W.F. in galls. per hour.	Equivalent depth running in pipe.	Velocity in ft. per second.
12 in. Branch from Leicester Street to No. 2 Pumping Station ...	12 in. 1 in 300	1,042	1¼ in.	1·25
15 in. Branch from Church Road to No. 2 Pumping Station	15 in. 1 in 300	7,291	3 in.	2·09
No. 2 Pumping Station to Water Street ...	15 in. 1 in 450	18,333	5½ in.	2·15
Water Street to Vearows Row	18 in. 1 in 600	20,416	5½ in.	1·94
Vearows Row to Main Pumping Station ...	21 in. 1 in 700	21,146	5⅝ in.	1·90

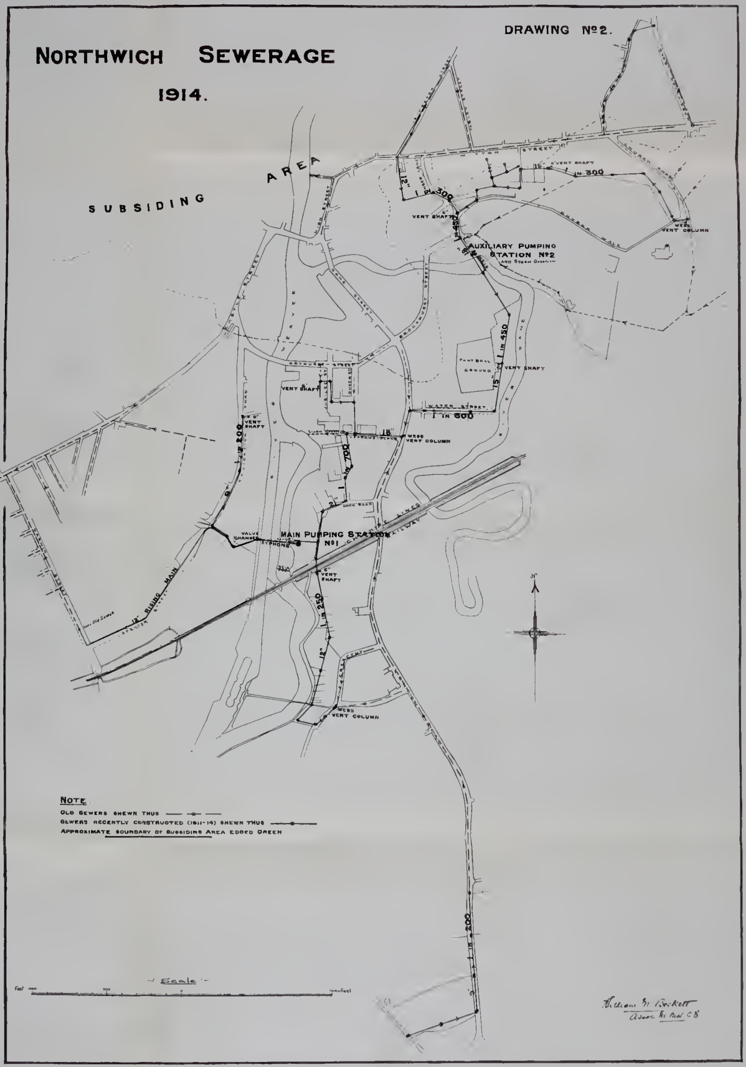

NORTHWICH SEWERAGE
1914.
DRAWING Nº2.
SUBSIDING AREA
WITTON STREET
CHURCH ROAD
CHURCH WALK
HIGH STREET
CASTLE STREET
LEICESTER STREET
TABLE STREET
SHEEP LANE
DANE STREET
BROCKHURST STREET
BATHURST STREET
JUBILEE ST
QUEEN ST
WATER STREET
STEPHENS PLACE
NAVIGATION ROAD
RIVER WEAVER
RIVER DANE
FOOT BALL GROUND
CHESHIRE LINES RAILWAY
AUXILIARY PUMPING STATION Nº2
AND STORM OVERFLOW
MAIN PUMPING STATION Nº1
SYPHONS
VALVE CHAMBER
VENT SHAFT
6" VENT SHAFT
WEBB VENT COLUMN
12" RISING MAIN
OLD SEWER
12"
15"
18"
1 IN 300
1 IN 450
1 IN 600
1 IN 700
1 IN 250
1 IN 200
N
NOTE
OLD SEWERS SHEWN THUS
SEWERS RECENTLY CONSTRUCTED (1911-14) SHEWN THUS
APPROXIMATE BOUNDARY OF SUBSIDING AREA EDGED GREEN
Scale
Feet
500
1000 Feet

FIG. 2.

In the above table allowance has been made for the fact that the pumps at No. 2 pumping station will raise the low level sewage and discharge it into the high level sewer at the rate of 10,000 gallons per hour. With this assistance it will be noted that, with the exception of the short 12 in. branch from Leicester Street, the actual velocity of flow in the dryest season will not fall below about 2 ft. per second, so that very little flushing will be required.

Provision is being made at the top end of the sewer in Church Road for connecting the waste water from some large swimming baths to the sewer in such a manner as to insure periodical flushing from this source. The maximum daily dry weather flow is assumed to be $2\frac{1}{2}$ times the average dry weather flow. In wet weather the sewers will deal with a flow of $\frac{1}{8}$th to $\frac{1}{4}$ in. rainfall per hour flowing off the building area draining to each sewer in addition to $2\frac{1}{2}$ times the average dry weather flow of sewage, and in addition also to the maximum rate (10,000 gallons per hour) at which the low level sewage is pumped into the high level sewer at No. 2 pumping station. To deal with excessive rainwater storm water overflows have been provided near both pumping stations, and at the bottom of Vearows Row.

Pipe Joints.—As the main intercepting sewers were laid outside the subsiding area they were jointed in cement in the dinary way. In the sinking area steel tubes have been used a few instances, and some experiments have been made with type of ball and socket pipe, and in other cases stoneware pipes with puddled clay joints surrounded with clay have been used. In the lower part of the town considerable leakage must take place, but as the material employed in raising the town consists of ashes from the salt and chemical works of the district, the leaking sewage is, no doubt, deodorised to a large extent. When the streets in the sinking portions of the town are raised, sewers, gas and water mains, and electric cables, are all raised and covered with a further layer of ashes. Considerable portions of the town have sunk and been raised over 20 ft. in the past 30 or 40 years.

The intercepting sewers have now been in use over 10 years and are working satisfactorily.

The storm water overflows at No. 2 pumping station consist of two troughs each 9 ft. long, one on the high level sewer and the other on the low level. Each trough is segmental in section and is to the same radius as the sewer to which it forms a cast iron invert bridging a chamber 9 ft. long. When the flow exceeds the quantity which the trough can deliver the excess flows over both sides into the chamber below and thence through an 18 in. pipe discharging into the river Dane.

Main Pumping Station.

The 21 in. main outfall sewer delivers into a storm water chamber at the side of the main pumping station. The storm water cill is formed along one side of the sewer and is designed to come into action when the flow exceeds 6 times the dry weather flow. The present population draining to the main pumping station is about 7,500, and the dry weather flow 150,000 gallons per day. Any excess over 900,000 gallons per day (or 37,500 gallons per hour) passes over the cill and thence along a 21 in. pipe discharging into the old course of the river Weaver. On the other side of the main sewer is a vertical cast iron plate with an adjustable orifice which is regulated so as to discharge the required maximum quantity (37,500 gallons per hour) into the pump well. The pump well is circular on plan, 27 ft. internal diameter and 13 ft. 6 in. deep, but the working depth of sewage is only 6 ft. 6 in. and working capacity about 23,000 gallons. The top water level is 33·00 above Ordnance Datum, or about 6 in. above the normal water level in the river. The excavations were carried down to level 33·00 in the open with side slopes of about 1½ to 1. At this level a ring of 6in. sheet piling 32 ft. internal diameter and 12 ft. long, was driven all round the site and the foundations were then excavated for and put in. The material excavated consisted of sandy marl with a few thin beds of sand and gravel. The 6 in. sheet piling was V-notched and driven in bays between ten king piles each 13 ft. 6 in. long by 12 in. by 12 in., equally spaced round the circle. After driving the king piles a 4½ in. by 4½ in. by ½ in. T iron walling was placed round the circle to form an internal guide for the sheeting.

The floor of the well is of 8 to 1 concrete 18 in. thick rendered with 1 to 1 cement 1 in. thick, and the side walls of 18 in. brickwork in cement with 12 in. of clay puddle between the walls and the sheet piling.

The engine house is immediately above the pump well and is also circular in form and 27 ft. internal diameter. The framework of the engine room floor is composed of rolled steel joists to which the engines and pumps are attached, the spaces between the joists being filled in with 4 to 1 fine concrete 4½ in. thick re-inforced with expanded metal and finished with a 1 in. layer of cement and granite chippings (1 to 1). The lower sides of all joists are boxed in with concrete. The main girder or joist carrying the floor is supported in the centre on a cast iron column 10 in. in diameter with end flanges 18 in. by 18 in. resting on a 6in. padstone and 3 ft. of concrete. The engine house is built of brickwork in cement, panelled, faced externally with Ravenhead rustic face bricks, and the walls finished in battlements. The design is further relieved with Ashlar string course and arches to doors and windows. The doors are of heavy oak and the window frames of wrought iron. The roof is of 4 to 1 re-inforced concrete 3½ in. thick finished externally with asphalte 1 in. thick and supported by 2-16 in. by 6 in. R.S. joists, which also act as runways for a 2 ton travelling crane.

The pumping plant consists of two sets of 7½ in. by 10 in. vertical treble ram pumps by Hayward, Tyler & Co., Ltd., each capable of delivering 9,000 gallons of crude sewage per hour against an actual head of 80 ft., exclusive of friction in rising main, each driven by a 12 B.H.P. Crossley gas engine—and of two electrically driven centrifugal pumps by the Rees-Roturbo Manufacturing Co., Ltd., each driven by a 38 B.H.P. General Electric motor, and each capable of delivering 36,000 gallons of screened sewage per hour against 80 ft. actual head. Provision is also made for installing a third electric motor and pump of equal power.

The gas engines use gas supplied by the local gas company at 2s. 6d.* per 1,000 c.ft., and the electric motors are driven by current supplied by the Northwich Electric Co., on the following terms, viz. : at 2d. a unit for 7½ per cent. of the maximum demand, and 1d. per unit for all current beyond that amount.

The sewage is delivered to the pump well through a horizontal wrought iron grating having 1 in. bars and 1 in. spaces. Here all sticks and large objects are arrested. The pump well is divided into two portions by a vertical galvanised wire screen. The screen consists of 10 frames or panels each 5 ft. wide and 3 ft. 9 in. high (in two tiers), formed of No. 4 B.W.G. galvanised wire spaced ½ in. apart, centre to centre and cross wired every 3 in. in height. The frames are of oak and are made to slide between 4 in. by 4 in. by ½ in. H steel and 4 in. by 2 in. by ½ in. channel steel uprights. The more liquid portion of the sewage passes through this vertical screen and is then raised by one of the electrically driven centrifugal pumps, the other pump and motor acting as a " stand by." Each motor and pump is started and stopped automatically by means of a simple throw over switch actuated by a float in the pump well. As soon as the water rises to a level about 6 ft. above the bottom the switch is thrown over and the motor starts, and when the water is lowered to within 6 in. of the bottom the switch is thrown back again and the motor stops. The reserve pump and motor are so adjusted that if the first motor refuses to start and the water rises to 6 ft. 6 in. above the bottom the second one will start working in its place. The current is switched on to each motor gradually by means of Adams' Igranic Series Relay type of self-acting rheostats, which automatically cut out the resistance in sections at appreciable intervals of time.

---

* All prices herein are pre-war.

The gas engines and ram pumps are started and stopped by hand and one set is run each day for about an hour to clear away the thick sludge which accumulates on the near side of the vertical screen.

In the event of the supply of electric current failing the two gas driven ram pumps would be capable of raising three times the dry weather flow of sewage.

The following are some of the reasons why the duplicate systems of pumping were adopted :—

(*a*) The gas works are situated in the subsiding area and a portion of the mains from the gasworks to the pumping station also pass through the subsiding area.

(*b*) Fractures of gas mains are not infrequent, and, owing to damaged joints caused by subsidence, nearly 33 per cent. of the gas manufactured is lost.

(*c*) The electric company's generating station is not within the subsiding area, but one of the substations is, and a considerable length of their cables pass through the sinking area and though they are not so seriously affected as the gas mains, certain areas are cut off from time to time by " shorts " due to subsidence.

(*d*) The slow speed ram pumps, dealing with crude sewage are more efficiently driven by gas engines. while the high speed centrifugal pumps, dealing with screened sewage are more efficiently driven by high speed motors.

In regard to the actual cost of pumping there is little to choose between the two methods on the terms and conditions existing at Northwich. In " fuel " cost the advantage is with the gas driven plant, but this is more than counterbalanced by the reduced capital cost of the electric plant and the fact that it is automatic in action. If gas driven ram pumps had been installed capable of dealing with the quantities dealt with by the electric pumps, they would have cost considerably more and have necessitated the provision of a larger engine house and an extra attendant for night duty. Taking electric current at the actual average pre-war price of 1¼d. per unit and gas at 2s. 6d. per 1,000 c.ft., and the actual running tests of the plant, the comparative " fuel " costs work out as follows :—

Electric pumps.—One pump raises and delivers 7,160 gallons against 80 ft. head in 10 minutes, consuming 4 units of electric current.

RIVER CROSSINGS

DRAWING Nº 5.

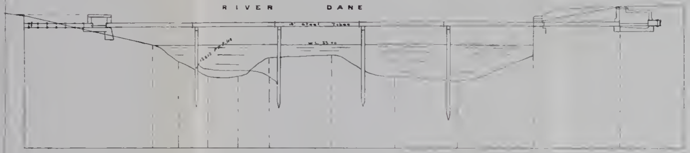
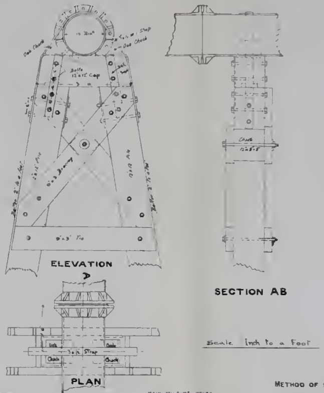
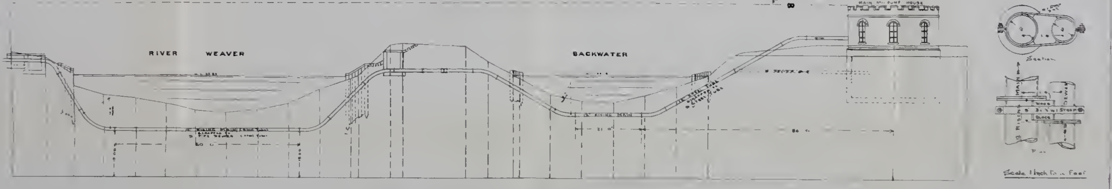


Fig. 3.

ENLARGED DETAILS





William B. Beckett
Assoc M Inst C E

Fig. 4

d.
Cost per 1,000 gallons raised ... ... 0·698

Gas-driven ram pumps.—One pump raises and delivers 9,844 gallons against 80 ft. head in one hour, consuming 162 c.ft. of town gas.

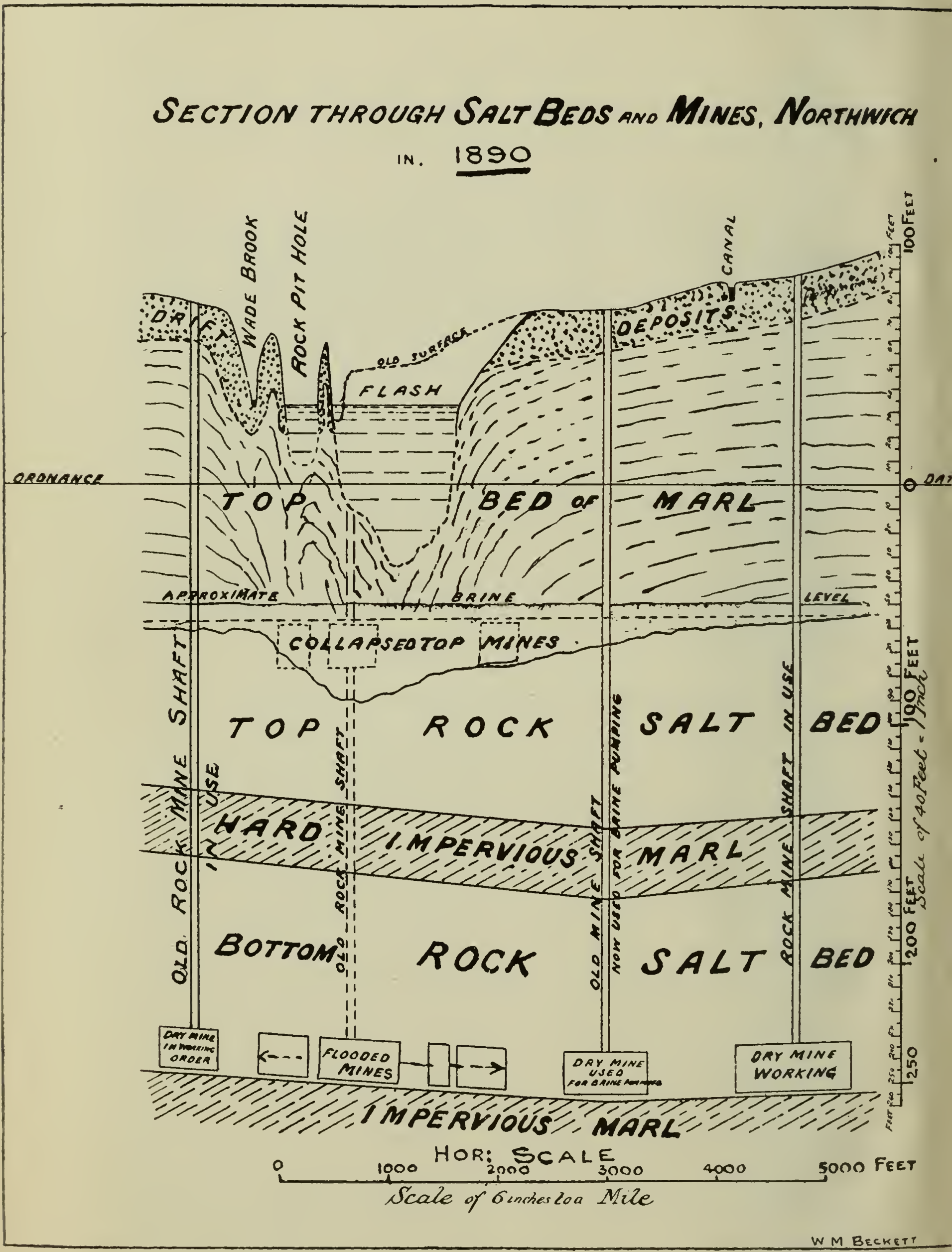
d.
Cost per 1,000 gallons raised ... ... 0·494

In dry weather one electrically driven pump runs in the aggregate 3½ hours in the 24, and pumps about 150,000 gallons of screened sewage, and one ram pump working from half-an-hour to one hour pumps 5,000 to 10,000 gallons of unscreened sewage. All the pumps deliver into one 12 in. rising main which is syphoned under the old course (or backwater) of the river Weaver across an island, and then syphoned under the navigable (canalised) course of the river (see Fig. 4) and thence up Spencer Street to Darwin Street, where it discharges into the top end of the gravitating system of sewers, which conveys the sewage to the Wallerscote outfall works.

When the Sewers in the area FF, Fig. 1 were constructed, it was anticipated that the sewage from the lower part of the town might be pumped into them and the main sewers from the top of Darwin Street to Wallerscote were made large enough to deal with it.

SYPHONS ACROSS RIVER WEAVER. (Fig. 4.)

The length of rising main under the bed of the river Weaver and the backwater consists of steel tubes 12 in. internal diameter by ⅜ in. thick. The sewage from Navigation Road and the adjacent district on the West side of the river is also conveyed to the main pumping station by means of a steel tube 9 in. in diameter by ⅜ in. thick. The 2 tubes are strapped together and syphoned under the two water courses in the manner shewn in Fig. 4. The tubes are of drawn steel and, together with the 15 in. steel tubes for the river Dane crossing, were supplied by the British Mannesman Tube Co., Ltd. The flanges are of welded iron screwed on to the ends of the tubes and machine faced. Each 12 in. joint is made with twelve ⅞ in. bolts and each 9 in. joint with eight ⅞ in. bolts. The trenches across the two waterways were dredged by the Weaver Navigation with men and plant supplied by their engineer, Mr. J. A. Saner, M.Inst.C.E. The two tubes for the backwater crossing were first jointed up and strapped together on the river bank and then hauled across and dropped into the trench. The two tubes across the main river course were similarly jointed up and strapped together and picked up by means of winches on two old barges, towed into position and dropped into the trench.



W M BECKETT
16 11 21

FIG. 4.

The actual operation of picking up the tubes and dropping them into position occupied only about 40 minutes.

In the main river crossing the two tubes were each about 123 ft. long and the combined weight, in air was about 6 tons 3 cwts., or 112 lbs. per foot run. The water displaced was about 80 lbs. per foot run, leaving the weight of the tubes when submerged only 32 lb. per foot run. They were consequently easily handled and placed *in situ*.

The ordinary working head of sewage in the 9 in. syphon is only 2 ft. in the total length of about 250 ft., but by an arrangement of valves in the manhole on the west side of the river, the full head of nearly 80 ft. in the 12 in. rising main can be utilised for flushing the 9 in. syphons. This flushing is done once a week and no difficulty has been experienced in keeping the syphon in good working order. The rising main from the end of the syphons to the existing sewer in Darwin Street consists of 12 in. cast iron pipes with a rising gradient all the way. With the exception of a few lead joints at the bends the joints throughout are turned and bored, each straight length being laid true to line and gradient. At each sharp bend the pipes are bedded in a mass of concrete to prevent the shock of the ram pumps loosening the joints.

All pipes and castings were supplied by the Stanton Ironworks Co., Ltd.

Subsidiary Pumping Station (No. 2).

The old low level sewers draining the area lettered DD in Fig. 1 which formerly discharged into the river Dane near No. 2 pumping station have been diverted into a pump well and the sewage (up to 10,000 gallons per hour) is pumped into the high level sewer. The well is 12 ft. in diameter and 20 ft. deep, of 14 in. brickwork in cement on a concrete floor 16 ft. 2 in. in diameter, the portion of the well below water level in the river is enclosed in a ring of 4 in. sheet piling 12 ft. long. As the foundations were in wet sand the concrete floor was re-inforced with some old steel rails. Inside the well is a vertical cylindrical wire screen 8 ft. in diameter and 7 ft. 6 in. deep, consisting of two tiers of framed screens fixed between rolled steel uprights. The bottom of the screen consists of a $\frac{1}{2}$ in. wrot iron plate 8 ft. 6 in. in diameter to which the uprights are fixed. A storm water overflow is provided on the low level sewer consisting of a cast iron trough 9 ft. 6 in. long of segmental section designed to take the flow up to 10,000 gallons per hour. Any excess passing over the sides of the trough into the bottom of the chamber and thence through 18 in. pipes into the river Dane. The overflow from the high level sewer passes into the same chamber and pipes to the river. The crude low level sewage discharges into the pump well on the outside of the cylindrical screen.

The pump house consists of an underground chamber 19 ft. long by 9 ft. 6 in. wide and 8 ft. 9 in. deep. The pumping plant consists of two electrically driven Rees-Roturbo centrifugal pumps, each capable of lifting 10,000 gallons per hour of screened sewage from the well and delivering into the high level sewer (maximum lift 12 ft.), and one electrically driven 6 in. by 8 in. ram pump (by Frank Pearn & Co.), capable of delivering 2,500 gallons per hour of crude (unscreened) sewage against a maximum head of 14 ft. The two centrifugal pumps are automatic in action being started and stopped by throw over switches actuated by floats in the pump well. These two pumps draw from the inside of the vertical screen, one set working and the other in reserve. The suction pipe from the ram pump passes through the bottom of the screen to the sumph below and is started and stopped by hand. It is run for a short time two or three times a week to remove the thick sludge that deposits at the bottom of the well. Each centrifugal pump is direct driven by a 2 B.H.P. motor running at 1,020 revs. per minute, consuming about 1·4 units of energy per hour, and the ram pump works at 60 strokes per minute and is gear driven by a 1½ B.H.P. motor running at 800 revs. per minute.

The 4 in. suction pipes are of drawn steel tubes and the main delivery pipe is 6 in. in diameter discharging into the high level sewer below the storm water chamber. The suction pipe from the ram pump is furnished with a telescopic joint, which permits the foot valve to be drawn up into the screen for examination when required.

The whole of the plant in this station was supplied by the Rees-Roturbo Manufacturing Co., Ltd., of Wolverhampton.

Sewer Ventilation.

The new sewers are ventilated by means of seven upcast shafts 25 ft. high and 6 in. in diameter and three Webb's gas ventilating columns fixed in the positions shewn in Fig. 2. With the exception of one or two ventilated covers about midway between each pair of upcast shafts the manhole covers are solid. The pump well at the main pumping station is ventilated by two shafts passing up to and through the roof, the air inlet being provided at the storm overflow chamber.

Sewage Outfall Works at Wallerscote.

The outfall works at Wallerscote were originally constructed in 1898 at a total cost, including land, of about £18,000, and are owned jointly by the Northwich Urban and Northwich Rural Councils. Prior to the construction of the pumping scheme for dealing with the lower portion of the urban district, the works dealt with the sewage from the higher portion of the urban district (lettered FF on Fig. 1) and embracing a population of 4,500 persons), and with sewage from a portion of the Winnington Parish in the rural district, embracing a population of about 1,900 persons. The works site embraces an area of about 15 acres adjacent to the river Weaver and the old works included :—

(i.) A screening and detritus chamber with storm overflow cill 16 ft. 9 in. wide delivering into a 30 in. diam. storm water pipe discharging into the river Weaver.

(ii.) Four large tanks each 75 ft. square by 6 ft. 6 in. depth of sewage having an aggregate capacity of about 914,000 gallons.

(iii.) Four primary contact beds each containing 120 c.yds. of coarse clinkers and four secondary contact beds each containing 150 c.yds. of fine clinkers.

(iv.) Seven acres of land underdrained and laid out as a filtration area.

(v.) A system of sludge drains from the detritus tank and septic tanks discharging into a pump well, whence the sludge was raised by a 6 in. centrifugal pump driven by a 7 B.H.P. Crossley gas engine and delivered either into one of 6 adjacent sludge pits, each about 80 ft. by 70 ft. by 2 ft. effective depth, or into one of two brick tanks each 61 ft. 6 in. by 39 ft. by 6 ft. 6 in. deep.

In 1911 the Author was instructed to report on the best means of remodelling the works so as to make them capable ot efficiently dealing with the sewage already flowing there as well as the additional sewage from the lower portion of the town which would have to be dealt with as soon as the new pumping station came into operation. On examining the then existing conditions it was evident that the capacity of the four large septic tank was much in excess of the requirements of the district, while on the other hand the capacity of the contact beds for dealing with the tank liquor from the population (6,400) then draining to the works was much too small.

The mode of working appeared to be to run the sewage into one of two tanks for about 3 months, passing the liquor thence through the 1st and 2nd contact beds and afterwards on to the filtration area for final treatment. At the end of 3 months the sewage was diverted into another tank and the contents of the first tank was pumped into the sludge pits and sludge tanks, the liquid effluent from which passed through a few sub-drains into the channels feeding the filtration area. The contact beds were practically choked with sewage and the purification.

so far as it was effected, was due almost entirely to the land filtration.

Dry Weather flow of Sewage.—The actual flow of sewage to the works was carefully measured in the large tanks by periodical measurements taken during a week in which no rain fell and it was found to average 127,555 gallons per day or almost exactly 20 gallons per head from a population of 6,400 persons then draining to the works.

The Urban district main outfall sewer is a 27 in. diameter stoneware pipe laid at a gradient of 1 in 1,250 and capable of delivering, when running full, about 175,000 gallons per hour. The Rural district outfall sewer is 18 in. in diameter, laid at a gradient of 1 in 800 and capable of delivering about 85,870 gallons per hour.

The works recommended by the Author and which have since been carried out include :—

(*a*) The remodelling and duplication of the detritus and screening chambers and the provision of gauge chambers, etc.

(*b*) The conversion of two of the original large tanks into three septic tanks and one storm water tank.

(*c*) The conversion of the other two large tanks into two octagonal percolating filters with revolving distributors 75 ft. in diameter and clinkers averaging 6 ft. 6 in. deep.

(*d*) The construction of a third octagonal percolating filter 6 ft. 6 in. deep with revolving distributor 60 ft. in diameter partly on the site of one of the old sludge tanks.

(*e*) The cleaning out and washing of the clinkers in the old contact beds, and the overhauling and improvement of the self-acting syphons for filling and emptying the same.

(*f*) Additional carriers on the filtration area.

(*g*) A separating chamber for regulating the flow of tank liquor to the contact beds and filtration area.

(*h*) The sub-draining of two of the sludge pits.

The works were designed to deal with a dry weather flow of 274,000 gallons per day, viz., 128,000 gallons per day from the gravitating areas, and 146,000 gallons per day pumped from the low lying portion of the district. After passing through the septic tanks the purification of the 274,000 gallons of dry weather sewage is dealt with in the following proportions :—

41,000 gallons per day on the contact beds at the rate of 38 gallons per c.yd. of clinkers.
63,000 gallons per day on the land at the rate of 9,000 gallons per acre.
170,000 gallons per day on the percolating filters at the rate of 70 gallons per c.yd. of filtrate.

Total 274,000 gallons per day.

The Urban and Rural outfall sewers discharge at the same invert level into a chamber, whence the sewage can be passed into either or both of 2 screening and detritus chambers each 30 ft. long and 16 ft. 9 in. wide, or, if necessary, the sewers may each discharge into one of the two chambers and the flow into each detritus chamber be separately gauged. At the far end of each detritus chamber is an overflow cill 16 ft. 9 in. long for taking excessive storm water. An 18 in. cast iron pipe passes from the end of each chamber under the overflow cill and conveys the sewage to the gauge chamber. This chamber is divided into three compartments. The 18 in. pipes deliver the sewage into the first compartment, and it then passes through a number of perforations in the bottom of the dividing wall into the second compartment. Here two cast iron gauge plates are fixed, each with a rectangular orifice 50 in. long and 2¾ in. deep, each calculated to discharge 36,000 gallons per hour when flowing full. The main storm overflow cills in the detritus tanks are at the same level as the top edges of the orifices in the gauge plates, so that when the flow exceeds the 72,000 gallons an hour which will pass through the two orifices, any excess will pass over the storm overflow cill. The third compartment has a gauge plate fixed at a lower level which allows any flow up to 42,000 gallons per hour to pass into a channel communicating with the three septic tanks. The third compartment also contains a cast iron open box 10 ft. long and 2 ft. wide, the top edge or lip of which is set level with the top of the orifice in the last named gauge plate. In the bottom of the cast iron box is a 9 in. cast iron elbow pipe communicating with the storm water tank. As soon as the flow into the third compartment exceeds 42,000 gallons per hour the excess (up to 72,000 gallons per hour) passes over the lip into the cast iron box and thence into the storm water tank.

Although, as previously stated, the dry weather flow from the lower part of the town is only 146,000 gallons per day, allowance must be made for the fact that it is pumped intermittently from the main pumping station, and that, instead of the maximum daily rate of delivery in dry weather being, say, three times the average, (or 304 gallons per minute), it is really delivered at the rated power of the pumps, which is 600 gallons per minute. To this must be added the dry weather flow from the gravitating areas, or, say, 100 gallons per minute, giving a rate of delivery to the septic tanks of 700 gallons per minute while the pumps are working. The flow is partially held up in the tanks during the pumping operations and is passed out at the rate of about 500 gallons per minute.

It may be remarked that on the test run, one electric pump raised 7,160 gallons in 10 minutes (or at the rate of 42,960 gallons per hour instead of the 36,000 gallons required in the specification), but as in practice each run lasts only 20 to 30 minutes in dry weather, and as moreover the sewage after being pumped has to pass through 1¼ miles of gravitating sewers from the top of Darwin Street to the outfall works, it does not pass into the gauge chamber at a greater rate than 36,000 gallons per hour. In wet weather the delivery from the pumps is 36,000 to 42,000 gallons per hour, and the quantity to be dealt with from the gravitating area is about 32,000 gallons per hour (six times the DWF). On these occasions 42,000 gallons per hour is passed through the septic tanks and 30,000 gallons per hour through the storm water tank, and thence on to the land. Of the 42,000 gallons per hour delivered to the septic tanks about 12,000 gallons passes over a special overflow on to the land. At these times the sewage from the pumps is diluted with five times its volume of storm water.

Septic Tanks.—The septic tanks are three in number, each 75 ft. long by 36 ft. 3 in. average width by 7 ft. 6 in. average depth of sewage, and with an aggregate capacity of 382,320 gallons, and were constructed by raising the old tank walls 15 in. and the water level 18 in. and constructing two new division walls, and in such a manner that the fourth division of the two old tanks is formed into a storm water tank. The tanks are constructed of brickwork in cement, and the old tank floors, which consisted merely of 4½ in. brick on edge paving, have been covered with 6 in. of 8 to 1 P.C. concrete. It was found necessary to raise the water level in the tanks in order to get sufficient head for dosing the percolating filters. The capacity of the tanks was in excess of the requirements, and only two tanks are now in use, one being held in reserve for future increased population draining to the works. The sewage can be passed into any one or more of the tanks over cills extending the full width of each tank, and is collected at the other end over a cill into a 12 in. half round stoneware channel communicating with the main outlet channel. These channels are carried on brick pilasters and project over the ends of the tanks, the concrete floors being re-inforced with expanded metal.

The main collecting channel is 3 ft. wide and is connected at the end of No. 1 Tank with a separating chamber. In No. 3 septic tank the channel returns along the side wall for a distance of 37 ft. and is made 4 ft. wide with a cast iron plate midfeather which extends the full length of the return channel and acts as a long overflow cill.

The separating chamber has a 6 in. cast iron pipe with a valve attached which allows a fixed quantity of tank liquor to pass into a channel flowing South and delivering directly on the filtration area, and another 6 in. pipe and valve delivers into a channel flowing North which allows another fixed quantity to be delivered to the contact beds. In each case a gauge board is fixed in the channel with a notch just large enough to deliver the required quantity when flowing full. The valves and gauge boards are adjusted so that 2,625 gallons per hour passes Southwards to the filtration area and 1,708 gallons per hour Northwards to the contact beds, and any excess over 4,333 gallons per hour passes over the midfeather in the return channel and thence to the percolating filters.

Percolating Filters.—The present dry weather flow of sewage dealt with on the percolating filters is 170,000 gallons per day, and at 70 gallons per c.yd. of filtrate, requires 2,430 c.yds. of clinker. The quantity in the three filters is 2,837 c.yds., thus allowing some little margin for increase of population (about 1,420 additional persons being thus provided for). When the total dry weather flow dealt with at the works exceeds 302,500 gallons per day it will be necessary to construct an additional percolating filter, and the works are designed so that several additional filters can be constructed on the North side of the present 60 ft. filter.

Before deciding to adopt revolving distributors, plans and estimates were also prepared for two alternative schemes, viz. :—

(*a*) A continuous filter 151 ft. 6 in. long by 75 ft. by 5 ft. 9 in. depth of filtrate (occupying the 2 old tanks), and another continuous filter 80 ft. long by 33 ft. by 5 ft. 9 in. deep fed with travelling distributors.

(*b*) Filters 151 ft. 6 in. long by 75 ft. wide by 7 ft. 3 in. deep (occupying the 2 old tanks) and fed by Stoddart drip distributors.

The travelling distributors require 2 ft. 3 in. head from septic tank water level to the top of the clinkers, whereas the revolving sprinklers (with dosing tanks) only require 1 ft. 6 ins. head and the Stoddart distributors were allowed 9ins. head. In each case the filters were designed to contain 2,820 cubic yards of clinker, and the relative pre-war estimates worked out as follows:

	£	s.	d.
(*a*) With Travelling distributors... ...	1,822	11	0
(*b*) With Stoddart drip distributors ...	2,013	10	6
(*c*) With Revolving distributors ...	1,496	12	0

75 ft. Filters.—The old brick on edge floors were removed from the two old 75 ft. tanks and a 6 in. concrete floor substituted with a fall of 1 ft. from sides to centre. The floors were then covered with Stiff's 4 in. aeration tiles, on which the clinker was spread to an average thickness of 6 ft. 2 in. A wall of large flat bedded clinker was built across each corner of each tank to give the octagonal form to the filters, the remainder of the filtrate consisting of medium grade clinker screened to pass through a 3 in. mesh and be retained by a 1¼ in. mesh screen. A perforated blue brick chamber 6 ft. in diameter in the centre of each filter contains the concrete base which supports the revolving distributor. One dosing tank, with a capacity of 2,100 gallons, feeds the two 75 ft. distributors, and another dosing tank with a capacity of 1,350 gallons feeds the 60 ft. distributor, and is also intended to feed an additional 60 ft. distributor to be erected when required.

The maximum daily quantity of liquor dealt with by the three percolating filters is 624,000 gallons, or an *average* of 433 gallons per minute, the arms of the distributors having been constructed so that each 75 ft. distributor will deliver at the rate of 166 gallons per minute, and the 60 ft. distributor at the rate of 100 gallons per minute.

The revolving distributors were supplied and fixed by Messrs. W. E. Farrer, Ltd., of Birmingham.

The dosing tank floors are constructed of 4 to 1 P.C. concrete re-inforced with expanded metal and supported on brick pillars. The side walls are of concrete 15 in. high finished with a 6 in. ashlar coping.

Contact Beds.—The four primary contact beds each contain 120 c.yds. of coarse clinker (2 in. to 4 in.) and the 4 secondary beds each 150 c.yds. of fine clinker (¼ in. to ½ in.). The beds are filled and emptied by means of Adam's patent syphons, each pair being charged and emptied once in the 24 hours. The effluent from the percolating filters and the contact beds is all passed on to the filtration area for final treatment before being discharged into the river.

Storm Water Tank.—The storm water tank is 75 ft. long by 36 ft. 3 in. average width by 7 ft. 6 in. average depth of water, and has a capacity of 127,440 gallons. It receives any excess flow over 42,000 gallons per hour and up to 72,000 gallons per hour at one end, and at the other end there is a floating arm which decants the surface water at the rate of about 20,000 gallons per hour and discharges it on to the filtration area. An emergency overflow cill is also provided at the far end of the storm water tank to come into action in prolonged periods of wet weather. This discharges into the storm water culvert.

Filtration Area.—The filtration area consists of two plots, one of 4 acres and the other of 3 acres. The liquid is fed on to the land by means of open carriers with overflow lips laid at a slight gradient (about 1 in 2,000).

The old carriers were spaced 50 to 60 yards apart, feeding 25 to 30 yds. each way. Intermediate carriers have now been fixed reducing the distance of feed to 12 to 15 yds. The new carriers are also laid in 3 or 4 steps of 1 in. in each length, so that the overflow can be limited to any desired section by means of stop plates. From each carrier lip the land falls away at a gradient of 1 in 36 and the whole is sub-drained with 6 in. open socketted pipes laid 10 yds. apart. The soil is mostly of a rather heavy sandy marl, and it was found necessary to cut grips from the distributing carriers, midway between the sub-drains to assist in distributing the liquid over the land.

GENERAL.

The whole of the constructional works, including the sewers, pump houses, storm overflows, etc., in the town and the alterations at Wallerscote outfall works were carried out by Messrs. S. Hutton & Co., of Northwich, Mr. Edmund Nield, acting as Clerk of Works.

The existing Witton outfall works are suffering severely from subsidence and will soon have to be abandoned. When this happens there will be no difficulty in diverting the sewage to the main pumping station, and provision has been made for this in designing the works.

The total pre-war cost of the works described in this paper was about £13,421, viz.: £4,010 on re-modelling the outfall works and £9,411 on the town portion of the scheme.

The latter item is made up as follows:—

	£	s.	d.
Sewers, manholes and storm overflows	2,937	2	3
Ventilating shafts	136	0	0
Syphons and rising main	1,516	7	0
River Dane crossing	160	15	9
Main pumping station (ex-plant)	985	3	7
Auxiliary Ditto. do.	490	6	5
Electric pumping plant (2 Stations)	776	10	4
Gas driven do. (Main Station)	513	12	6
Roads and fencing	246	18	6
Overhead crane and sundries	156	2	6
Total Works cost	£7,918	18	10
Land and easements, law charges, engineering, clerk of works and sundries	1,492	7	2
	£9,411	6	0

Discussion.

Mr. J. F. J. Reynolds, M.Inst.C.E., A.M.S.E., said in referring to the syphon crossings of the river Weaver and backwater, shewn on the lower portion of Fig. 4, that it was not clear why a double syphon was used, as the maximum increase in depth of trench necessary for a single syphon for both crossings would not appear to have been more than about 18 ft., with a saving in length and four bends in the 12 and 9 in. mains. From the description of the method of laying given at the bottom of p. 231, it appeared this might have been done to allow each syphon to be laid independently and the junction made above top-water level. It would be interesting to know if any other local circumstances influenced the design of these crossings.

Mr. Wm. Brown said he would make a few brief remarks on two main trains of thought which spring from two opposite sets of conditions. One set has reference to things as they were, the other to things as they should be.

From the point of view of the actual, he congratulated the lecturer upon the interesting description he had given us of an exceptional and difficult piece of work successfully carried out. But when he turned to the ideal, congratulation gave place to exasperation, for the actual was seen to be a direct negation in regard to every practical requirement of the ideal. And the prospect now ? Chaos everywhere. How caused ? By wrong conceptions of the real problem, erroneous practice, professional piques and jealousies, departmental conventions, factious local politics and much else. With what result ? Expenditure on an unnecessary scale, and that huge expense notwithstanding, the exaction of an appalling toll of preventable disease and death from the community every year. Of course the lecturer had nothing to do with that. He had to work under the actual existing conditions. But the blame lay heavily on the shoulders of all whose duty it was to better the bad conditions.

Let us just inquire what the motive behind the author's work was. Ideally was it not a desire to improve the health conditions of Northwich ? What was the result ? The author did not say. That omission was surely significant. Again, take the remark at p. 225, "this portion of the scheme has consequently not been carried out." The incident referred to might logically be argued as indicating apathy on the part of the local authority with regard to the health interests of Northwich. Thus, a scheme that was deemed necessary in these interests was got out, it was dropped by the local authority because the central authority could only advise that it should be paid for out of the rates when the work was completed. Presumably, no alternative means were considered whereby the health and lives involved in the dropping of the scheme could be protected in the meantime.

The author had dealt with sewer ventilation. From the health point of view this was a most important matter—logically, the most important—in any scheme of sewerage at the present time. It was of vital interest to Northwich that there should be no failure there. A serious mistake at the outfall, for instance, might not affect the health of Northwich by a single headache, but a breakdown in the sewer ventilation must inevitably cause damage both to health and life, such damage varying in intensity with the extent and nature of the breakdown. Under the system described, a breakdown was unavoidable in the course of every year, as surely as the weather changed to high temperatures and rainless days.

The author spoke of solid, or blocked, manhole covers. The speaker said he lived in a healthy suburb in the north of London. The local authority had tried various methods with a view to secure the proper ventilation of their sewers. All these expedients were wrongly based and had proved failures. Some sewers had been fitted with blocked manhole covers. Thus money was spent in building a ventilating shaft and it was at once rendered useless by fitting it with a blocked cover! That is typical of much else in connection with our sanitary methods. The sewer in the avenue in which he lived had been fitted with blocked covers. They were surrounded by open fields. The residents belong to a well-to-do middle class, chiefly young married couples who took an intelligent care of their children. Everything, in fact, was in accordance with the ideas of child welfare enthusiasts and yet the avenue was seldom, if ever, free from foul air disease. The only explanation of this that he could find was the bad sewer ventilation.

The meeting might be aware of the serious breakdown of the London disease prevention methods which even then was claiming its victims in unprecedented numbers. Up to and including the week ending 10th September, the cases in the London Hospitals for infectious or foul air diseases, *i.e.*, enteric fever, measles, scarlet fever, whooping cough, and diphtheria, had for several weeks been about 5,300, a very unsatisfactory figure. Then a phenominally rapid rise took place as could be seen from the official figures as follows:—

No.	37	week ended	September	17th ...	5,973
,,	38	,,	,,	24th ...	6,491
,,	39	,,	October	1st ...	7,052
,,	40	,,	,,	8th ...	7,858
,,	41	,,	,,	15th ...	8,534
,,	42	,,	,,	22nd ...	8,789
,,	43	,,	,,	29th ...	9,194

No.	44	week ended	November	5th ...	9,353
,,	45	,,	,,	12th ...	9,358
,,	46	,,	,,	19th ...	9,300
,,	47	,,	,,	26th ...	9,246

The variations shown above refer almost exclusively to the scarlet fever and diphtheria cases. The following details of the cases for the week ended November 12th, will serve to illustrate the details of the other weekly totals. They are :—

Ent. fev.	Measles.	Scarlet fev.	W. Cough.	Diphtheria.		Total.
27	38	6,233	29	3,031	=	9,358

The hospitals were, in fact, filled to overflowing and many cases had to be refused admission. Many others were discharged before they were ready for leaving.

A point of special interest was that the exceptional meteorology of the late Spring, Summer, and late Autumn weeks corresponded with the phenomenal outbreak of foul air disease now in progress, by acting on the sewer air in agreement with the principles he had explained in a paper read before the Society, and applied to other and different meteorological conditions. Briefly, this was apparently what happened. For many weeks the weather was favourable to the production of sewer gas which became progressively more noxious. This produced lowered vitality and many cases. Then the temperature took a rapid downward course, lowering the vitality to a phenomenal degree and producing cases in the unprecedented numbers given above, which of course do not include all the cases that occurred.

The fact is our whole system of disease prevention requires a thorough exploration into all the correlated circumstances. If our system of infectious hospitals were properly based the fact that so many cases had to be summarily dealt with would have meant a serious menace to the public health. But the value of infectious hospitals was questionable. An official said to a friend of his, " it is not our business to prevent diseases but to cure them when they occur."

That remark was a striking and, withal, ominously accurate snapshot of a situation in which the actual falls miserably short of the ideal, and not only so, but in some respects amounts to a literal perversion of it. Thus the sound old maxim " prevention is better than cure," in official thought and practice sometimes really reads, " cure is better than prevention."

Mr. H. C. H. Shenton, M.I.Mun.E., F.S.E., said that the difficulty of laying sewers under ordinary conditions was considerable, but that when sewers had to be laid in unstable ground subject to serious subsidence, the difficulty was enormously increased and it was evident that the author had worked under conditions which were altogether abnormal and where ordinary methods would not apply. The method of laying pipes with clay joints surrounded with puddled clay would not be suitable under any ordinary conditions, though no doubt the author had some special reason for working in this manner. Having regard to the fact that a great deal of sewerage work had to be done on the Continent in the War area where the ground had been undermined, French engineers were, at the present time, having to deal with a similar problem to that encountered at Northwich, and they were asking for information as to the practice in this country. It was, therefore, to be regretted that the author had not dealt more fully with the subject. He would like to ask the author whether a flexible joint would not be advantageous in the circumstances. The speaker referred to a joint mentioned in the Pro. Inst. C.E., Vol. LXXIV., p. 176, used for a 22 in. main, which settled without leakage a vertical distance of 13 ft. in a length of about 400 ft., owing to a subsidence of the ground caused by mining operations. He also referred to a flexible joint described in *Engineering*, of July 9th, 1869, p. 34, in which flexibility was obtained by an enlargement of the socket at the shoulder, and to the ordinary ball and socket joint and to the Victaulic joint recently exhibited in London. It did not appear to be impossible to lay sewers, in unstable ground, that would stand a certain amount of settlement without leaking.

Mr. H. Bentham, M.S.E., congratulated Mr. Beckett on the excellent paper he had given to the meeting, and asked whether any complaints had been made by the brine-pumpers concerning the leakage of sewage into the brine-pits when settlements occurred in the sewers.

The figures given of the loss of gas during the year, amounting to thirty per cent. appeared very heavy, and the speaker inquired whether any cases had occurred where faults in the electric cables at the same time had led to serious results.

The use of adjustable joints for the sewers with a view to counteract settlements, could only be done where minor subsidences took place, as immediately sewers were seriously out of alignment it always meant trouble.

Mr. A. S. Everett, P.A.S.I., M.S.E., said that he had listened to the paper with much interest, particularly in reference to the question of flexible joints. While avoiding fractures and leakage, these would not overcome the equally important difficulty of maintaining alignment and regularity of gradient.

When a short section of very bad ground, liable to repeated sinking was concerned, it might be worth while placing the sewer, where of comparatively small diameter, in a subway or tunnel of sufficient diameter to admit of adjustment after movement of the latter, which would of course carry the sewer with it. Adjustment could be carried out quickly under such conditions and with a minimum of disturbance of surfaces. The plan would deal only with movements of limited extent. The subway might be of steel plate or perhaps cast-iron tubbing, and with wide expansion joints, such as could be made with some bituminous compound of a plastic nature, which would give, and still remain watertight, or be capable of being caulked from the inside when the joint opened at the bottom. It was recognised that this idea would probably be of limited application, and to the practicability of flexibly jointing the cast-iron tubbing or steel plate tubes, in such a way as to admit of resealing when a movement had disturbed them. Possibly the Victaulic joint was applicable. In waterlogged ground, repairs could be done under compressed air. Joints of sewer would be preferably made by a flexible or expansion method, and secured so as to be capable of more or less ready disconnection and re-connection. The pipes would be in short lengths to lessen the movement per joint.

THE AUTHOR'S REPLY.

The Chairman asked what would be the relative cost of constructing a tunnel for conveying the sewage by gravitation to the Outfall works compared with that of pumping the sewage as carried out. As the sewage was delivered at the pumping station at a level only 1 or 2 ft. above the river water level and as it had to be delivered at the Outfall works about 20 ft. above river level (in order to be treated on the percolating filters and subsequently passed through the filtration area), it was evident that pumping had to be resorted to.

As the suggested tunnel would have had to be over a mile long, laid at a rising gradient, the total head required to deliver the sewage to the Outfall works would have been nearly 40 ft. The cost of constructing the tunnel would have considerably exceeded the capitalised additional cost of raising the sewage 80 ft. instead of 40 ft.

In reply to Mr. Reynolds, the author was of opinion that if the syphon had been constructed and laid in one length, it would have been unwieldy and difficult to lay in position, and that the extra excavation and dredging required in forming the trench across the island would have been more costly than the few special bends required in the construction of the two separate syphons. One long syphon would have been subject to larger stresses and these would have entailed heavier construction and greater cost.

Mr. Brown includes the author (though in a minor degree), in his sweeping condemnation of all existing systems of sewer ventilation. The subject was too large to be dealt with in a short reply to his criticism. That there was still considerable room for improvement in sewer ventilation, as in other branches of sanitation, was no doubt true, but the author, after once more reading Mr. Brown's paper, was still unconvinced that the solution lay in dispensing with up cast shafts and opening all manhole covers to act as inlets *and outlets*. If some acted as inlets others must act as outlets, discharging sewer gas in the worst possible manner, unless some means could be devised for entirely deodorizing the sewage as it flowed along the sewers, and more particularly the deposited slime due to the fluctuating level of the sewage in the pipes or culverts, the ideal condition aimed at by Mr. Brown will not be attained.

At Northwich, the manhole covers were not all blocked, the sewers were divided into sections containing 4 or 5 manholes. One or two manholes at the lower end of each section had open ventilated covers, the upper 2 or 3 manholes being provided with blocked covers and an upcast shaft or Webb ventilating column was connected to the upper end of the section, and by this means a direct circulation was set up from end to end of the section. It was possible that for a few hours in the daytime in hot weather the circulation of the air might be checked, but, in the night time it would start again and thus clear away any temporary accumulation of sewer gas. In the case of the Webb ventilating columns, the air for feeding the flames was drawn from the sewer continuously, thus maintaining the ventilation.

The author desired to express his appreciation of the time and thought given by Mr. Brown to the study of this important question and his efforts to approach a high ideal in solving the problem of sewer ventilation.

In reply to Mr. H. C. H. Shenton, the author was not called upon by the Urban Council to deal with the general system of sewers in Northwich, his instructions being to report on the best means of intercepting the various outfall sewers which were discharging crude sewage into the river, to collect the intercepted sewage and to deliver it to the existing Outfall works at Wallerscote, to be there properly treated before being discharged into the river.

With this object in view, he laid out his system of intercepting sewers on land that was not subject to subsidence and consequently did not make any special study of the best form of joint for pipes in subsiding area. In the few cases in which he had to tap the existing sewers in subsiding land, he used Mannesmann Steel tubes with wide joints, and, in the case of small branch sewers, he laid them in clay with puddled clay joints as described in the paper. He regrets that he cannot add much useful information on this point.

He had recently had the opportunity of inspecting the Victaulic joint and was of opinion that this joint was admirably suited for use in subsiding areas, both on account of its flexibility and also of the ease with which the pipes can be taken up and re-laid to line and gradient.

In reply to Mr. Bentham, the author believed that no complaints had been made by the brine pumpers concerning the leakage of sewage into the brine mines. These mines underlay a thick bed of impervious marl, the only immediate connection being the artificial shafts driven through the marl. The bulk of the water which found its way down to the " Rock head " or upper layer of salt and was there converted into brine, was supplied by the rainfall and natural streams at the outcrop some miles away.

Only one or two small explosions had occurred in the last 20 years due to gas accumulation in electric boxes, and in no case was the result serious. Care was taken to ventilate the boxes and prevent accumulations taking place.

The author agreed that as soon as a subsidence became serious the sewers must be taken up and re-laid.

In reply to Mr. A. S. Everett, the author considered that the cost of constructing and maintaining a subway or tunnel in badly subsiding ground would more than counterbalance the advantage it might give of inspecting and re-aligning the pipe sewer inside it. A further difficulty lay in the fact that within the subsiding area the bad subsidences were constantly varying in position and in the extent to which the subsidence took place.

In conclusion the author desired to express his thanks for the kind reception accorded to the paper.

ANNUAL GENERAL MEETING.

The Twelfth Annual General Meeting of the Society was held in the offices of the Society, 17, Victoria Street, S.W. 1, on Monday, 12th December, 1921, at 6 p.m., the Past-President, Mr. Burnard Geen, being in the Chair.

The notice convening the meeting was read.

The Secretary read the Report of the Scrutineers on the result of the Postal Ballot for the election of the Council and officers for the year 1922. (See page 257.)

The Report of the Council for the year 1921 was read and adopted.

Messrs. Begbie, Robinson, Cox and Knight, Chartered Accountants, were re-elected as the auditors of the Society for the ensuing year.

A vote of thanks was accorded to the Scrutineers, Messrs. C. Cunningham and L. E. Desbleds, for their services ; and to Mr. D. B. Butler for having acted as Hon. Treasurer since 1906.

Finally, a vote of thanks having been accorded to Mr. Geen for taking the Chair, and the President, the Rt. Hon. Lord Headley, for his year of office, the meeting closed at 6.26 p.m.

THE SOCIETY OF ENGINEERS (INCORPORATED).

BALANCE SHEET 31st December, 1920.

Year ended *31st Dec., 1919.* £ s. d.	LIABILITIES.	£ s. d.	£ s. d.
321 12 5	*Sundry Creditors*		227 13 7
23 6 8	*Subscriptions in Advance* ...		95 17 2
	Life Membership Account—		
72 2 10	As per last Balance Sheet ...	68 10 8	
—	*Add*—Life Membership Subscription received	21 0 0	
		89 10 8	
3 12 2	*Less*—5 per cent. Transferred to Income on account of Life Subscriptions expired ...	3 8 6	86 2 2
68 10 8			
	Benevolent Fund Account—		
72 18 8	As per last Balance Sheet ...	75 17 0	
2 18 4	*Add*—Interest at 4 per cent. ...	3 0 8	78 17 8
75 17 0			

Year ended *31st Dec., 1919.* £ s. d.	ASSETS.	£ s. d.	£ s. d.
	Cash—		
22 14 4	At Bank—Current Account ...	72 7 3	
53 13 9	,, Deposit Account ...	57 3 1	
10 14 10	In hands of Secretary	6 9 6	135 19 10
87 2 11			
	Sundry Debtors—		
92 11 0	Subscriptions in arrear and received up to 19th May, 1921	23 2 0	
3 6 6	Advertisements in Journal, etc.	2 18 0	
—	Excess Premium refunded 1921	1 6 0	27 6 0
95 17 6			
	Investments—		
524 19 0	£606 London & N.W. Rly. 3 per cent. Perp. Debenture Stock at 66½ as per last Balance Sheet	524 19 0	
278 13 6	£300 India 3½ per cent. Bonds at cost as per last Balance Sheet	278 13 6	
803 12 6		803 12 6	
280 0 0	*Less*—Reserve for Depreciation	338 0 0	465 12 6
523 12 6	(The Market Value of these Securities at 31st December, 1920 was £465)		

	Accumulated Fund Account being Excess of Assets over Liabilities		
551 7 5	as per last Balance Sheet ...	277 0 5	
	Deduct—Balance from Income		
109 7 0	and Expenditure Account ...	22 0 11	
442 0 5		254 19 6	
	Deduct—Additional Reserve for Depreciation of Securities to		
165 0 0	make up total Reserve of £338	58 0 0	
			196 19 6
277 0 5			
£766 7 2			£685 10 1

	Office Furniture—		
19 0 8	As per last Balance Sheet ...	17 2 8	
	Added since	—	
		17 2 8	
1 18 0	*Less*—Depreciation at 5 per cent.	0 17 2	
			16 5 6
17 2 8			
	Library—		
21 7 6	As per last Balance Sheet ...	19 5 2	
2 2 4	*Less*—Depreciation at 10 per cent.	1 18 6	
			17 6 8
19 5 2			
	Stocks on hand—		
22 13 0	Transactions and Journals ...	22 10 0	
0 13 5	Law Lectures	0 9 7	
			22 19 7
23 6 5			
£766 7 2			£685 10 1

THE SOCIETY OF ENGINEERS (INCORPORATED).

THE BESSEMER PRIZE FUND.

Year ended *31st Dec., 1919.* £ s. d.		£ s. d.	£ s. d.
122 8 4	As per last BalanceSheet	102 11 2	
18 10 0	*Less*—Investment Depreciation A/c	5 11 0	
103 18 4		97 0 2	
3 17 10	*Add*—Income form N.E. Rly. Debenture Stock	3 17 8	
107 16 2		100 17 10	
5 5 0	*Deduct*—Cost of Premium ...	4 12 3	
			96 5 7
£102 11 2			£96 5 7

Year ended *31st Dec., 1919.* £ s. d.		£ s. d.
96 4 0	£185 N.E. Rly. 3 per cent. Debenture Stock (At Market Value, 31st December, 1920)	90 13 0
6 7 2	Cash in hand	5 12 7
£102 11 2		£96 5 7

THE NURSEY PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.
37 0 7	As per last Balance Sheet ...	32 10 2	
2 12 10	*Less*—Investment Depreciation A/c	2 6 2	
34 7 9		30 4 0	
1 5 5	*Add*—Income from Hammersmith and City Rly. Ordinary Stock	1 5 6	
			31 9 6
35 13 2			
3 3 0			
£32 10 2			£31 9 6

PRIZE FUND.

£ s. d.		£ s. d.
29 14 0	£33 Hammersmith & City Railway Consolidated Ordinary Stock ... ... (At latest available quotation to 31st December, 1920)	27 7 10
2 16 2	Cash in hand	4 1 8
£32 10 2		£31 9 6

THE BERNAYS PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.	£ s. d.		£ s. d.	£ s. d.
21 5 7	As per last Balance Sheet ...	19 6 0		17 0 7	£13 N. & S.W. Junction Rly. Stock (At latest available quotation to 31st December, 1920)		14 11 2
—	*Less*—Investment Depreciation A/c	2 9 5					
21 5 7		16 16 7		2 3 9	Cash in hand on Capital A/c ...	2 3 9	
0 12 11	*Add*—Income from N. & S.W. Junction Railway Stock ...	0 12 11		0 1 8	Income A/c ...	0 14 7	2 18 4
21 18, 6			17 9 6				
2 12 6				2 5 5			
£19 6 0			£17 9 6	£19 6 0			£17 9 6

We have prepared the above Balance Sheet and Income and Expenditure Account from the Books and Vouchers of the Society, and have obtained all the information and explanations we have required. In our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of our information and the explanations given us and as shewn by the Books of the Society.

3, Raymond Buildings,
Gray's Inn, London, W.C.1.
27th May, 1921.

(Signed) BEGBIE, ROBINSON, COX & KNIGHT,
Chartered Accountants.

THE SOCIETY OF ENGINEERS (INCORPORATED).

INCOME AND EXPENDITURE ACCOUNT, FOR THE YEAR ENDED 31ST DECEMBER, 1920.

Year ended *31st Dec., 1919.* £ s. d.	EXPENDITURE.	£ s. d.	£ s. d.
382 0 3	To Printing " Transactions " ...	296 15 4	
55 5 8	*Less* Sales and Advertisements	37 5 11	259 9 5
326 14 7			
	,, *Administration Expenses*—		
300 0 0	Salary of Secretary	300 0 0	
85 0 0	Rent of Offices...	93 10 0	
19 11 10	Fuel, Lighting and Office Cleaning	19 2 4	
82 13 3	Postage, Telegrams, Carriage and General Expenses ...	82 18 2	
143 3 6	Stationery and General Printing	65 9 10	
16 16 0	Audit Fee and Law Charges ...	32 15 5	593 15 9
647 4 7			
	,, *Meeting Expenses*—		
8 8 0	Hire of Rooms...	9 14 6	
4 7 7	,, Lanterns	1 1 0	
22 16 4	Reporting Meetings	14 9 3	
23 11 2	Refreshments for Members at Ordinary Meetings, etc. ...	19 11 11	44 16 8
59 3 1			
1 18 0	,, Depreciation of Office Furniture		0 17 2
2 2 4	,, ,, Library ...		1 18 6
2 18 4	,, Interest on Benevolent Fund		3 0 8
9 2 0	,, Cost of Premiums presented by the Society		9 3 6
—	,, " Geen Premium " per contra		5 5 0
£1,049 2 11			£918 6 8

Year ended *31st Dec., 1919.* £ s. d.	INCOME.	£ s. d.	£ s. d.
775 6 2	By Subscriptions		751 17 3
87 3 0	,, Admission Fees		88 14 6
0 15 5	,, Interest on Deposit		3 9 4
41 5 0			
	,, *Interest on Investments*—		
12 14 6	London & North-Western Rly. 3 per cent. Debenture Stock	12 14 6	
7 7 0	India 3½ per cent. Stock ...	7 7 0	20 1 6
20 1 6			
7 3 7	,, Sundry Receipts		6 8 2
1 1 3	,, Special Donation		10 0 0
7 0 0	,, Donation from President on account of Premiums presented by the Society ...		10 10 0
—	,, Donation from President for " Geen Premium "		5 5 0
109 7 0	,, Balance, being Excess of Expenditure over Income, carried to Accumulated Fund Account		22 0 11
£1,049 2 11			£918 6 8

REPORT OF THE COUNCIL FOR THE YEAR 1921.

In presenting their Twelfth Annual Report of the Incorporated Society, the Council have to state that the membership at this date is as follows :—

Hon. Fellows	21
Fellows...	44
Members	302
Associate Members	208
Associates	76
Total	651

and that 75 Corporate Members and Associates were elected during the year 1921.

The following are now the Associated Societies, many of which joined during the year :—

Battersea Polytechnic Engineering Society.
Birmingham Association of Mechanical Engineers.
University of Birmingham Engineering Society.
Crystal Palace Engineering Society.
Derby Society of Engineers.
Gloucestershire Engineering Society.
The Polytechnic (Regent Street) Engineering Society.
Queen's University (Belfast) Engineering Society.
Stoke-on-Trent Association of Engineers.
Wolverhampton and District Engineering Society.

The combined membership of these Associated Societies is 1,690.

Under Clause 6 of the Regulations for the Association of Engineering Societies, the members of these societies are entitled on the payment of a small annual subscription to receive post free the JOURNAL OF THE SOCIETY OF ENGINEERS and a number of members have already availed themselves of this arrangement.

The Council have much regret in recording the deaths of the following during the year :—

Sir Charles Douglas Fox, M.Inst.C.E., M.I.Mech.E., M.I.E.E., who for so many years was an Honorary Fellow of this Society, and one of the three Trustees, an obituary notice of whom appears at p. 703 of *Engineering*, November 18th, 1921.

Mr. Hermann Sloog, M.Soc.Ing.Civ. (France), A.M.I.E.E., M.S.E., one of the Members of Council of the Society, an obituary notice of whom appears elsewhere.

Members.

S. N. Chandabhoy.
J. Love.
P. F. Mackenzie-Richards.
Hon. A. O. Sachse.
T. H. Seaver.

Associate Members.

B. M. Banerji.
T. B. Vakil.

Associate.

G. J. Money.

MEETINGS.

During the year seven Ordinary Meetings, nine meetings of the Council, and eighteen meetings of various Committees have been held.

The following visits to works were made by members and their friends :—New (King George) Dock, North Woolwich, June 15th, 1921 ; Littleton Reservoir, July 20th, 1921 ; Croydon Aerodrome September 24th, 1921.

PAPERS AND PREMIUMS.

The Rt. Hon. Lord Headley, B.A., M.Inst.C.E., I., delivered his Presidential Address on February 7th, when he dealt chiefly with new inventions and scientific discoveries.

The following papers were contributed during the year for discussion at meetings or for publication in the Journal :—

"Some Modern Engineering Practice in America," by Capt. R. W. A. Brewer, A.M.I.C.E., M.I.A.E., F.S.E.

"The Motor Car Pneumatic Tyre," by Lieut. J. C. Ferguson, A.S.E.

"The Physical Properties of Clay" (third paper), by A. S. E. Ackermann, B.Sc. (Engineering), A.C.G.I., M.Cons.E., A.M.I.C.E.

"Visit to Inchinnan Aerodrome to view Airship R.36," by W. R. Taylor, A.M.I.Mech.E., A.M.S.E.

"Cohesion," by Dr. Herbert Chatley, D.Sc. (Engineering).

"Artillery from the Scientific and Engineering Point of View," by W. S. Bamford, A.S.E.

"Coal and its Bye-Products," by J. R. L. Allott, M.I.Min.E., F.S.I.

"The Winning of Tidal Lands in British Guiana," by GERALD O. CASE, A.M.E.I.C., Assoc.M.Am.Soc.C.E., M.S.E.

"Extraction Turbines," by C. H. NAYLOR, A.M.I.C.E.

"Northwich Sewerage and Sewage Disposal Works," by W. M. BECKETT, M.B.E., A.M.Inst.C.E., M.S.E.

The thanks of the Society are tendered to all authors of papers and premiums have been awarded as follows :—

The President's Gold Medal to Mr. G. O. CASE.

The Bessemer Premium, value £5 5s., to Mr. R. W. A. BREWER.

The Nursey Premium, value £3 3s., to Mr. A. S. E. ACKERMANN.

The Society Premium, value £3 3s., to Mr. W. M. BECKETT.

The Geen Premium, value £5 5s., to Mr. C. F. MOORE, of the Crystal Palace Engineering Society, for his paper on "Locomotives of the London and North Western Railway."

COUNCIL AND OFFICERS FOR 1922.

The result of the Postal Ballot for the election of Council and Hon. Officers for 1922 is as follows :—

As *President :* T. J. GUERITTE.

As *Vice-Presidents :* A. MARSHALL ARTER, G. A. BECKS, A. STEWART BUCKLE.

As *Members of Council :* D. C. FIDLER, C. CONNOR, R. W. R. TWELVETREES, G. NOBLE FELL, W. J. HADFIELD, F. PURTON, G. O. CASE, J. S. E. DE VESIAN, H. E. BERGMAN.

As *Members of Council from the class of Associate Members :* J. F. J. REYNOLDS, R. GREGORY.

As *Hon. Secretary and Hon. Treasurer :* C. T. WALROND.

The thanks of the Society are due to Messrs. C. Cunningham and L. E. Desbleds, the scrutineers of the ballot lists.

INDEX TO TRANSACTIONS, 1910-21.

The date following each title indicates the year of publication, and the page reference is to the volume of Transactions for that year.

PAGE

Abattoirs (*see Slaughter*).
Accounts, Engineering. H. McFarland Davis ... 250
Accretion at Estuary Harbours on the South Coast of England. Gerald O. Case, 1913 ... 205
Adventures, Great Engineering. E. Cressy, 1920 ... 133
Airship R. 36, Visit to Inchinnan Aerodrome to View. W. R. Taylor, 1921 ... 131
Annual General Meeting, 1910 ... 292
——— 1911 ... 408
——— 1912 ... 343
——— 1913 ... 277
——— 1914 ... 344
——— 1915 ... 283
——— 1916 ... 271
——— 1917 ... 357
——— 1918 ... 215
——— 1919 ... 315
——— 1920 ... 311
——— 1921 ... 249
Artillery during the War, The Development of. Capt. M. E. de Jarny, 1919 ... 221
——— from the Scientific and Engineering Point of View. W. S. Bamford, 1921 ... 141
Assessment of Engineering Undertakings, The. W. G. Cooke, 1920 ... 113
Attraction, Law of, for Molecular Force. Dr. Herbert Chatley, 1919 ... 192
Axles of Railway Wagons. H. Kelway-Bamber, 1918 ... 189
Balance Sheet and Accounts, 1911 ... 114
——— 1912 ... 31
——— 1913 ... 65
——— 1914 ... 56
——— 1915 ... 46
——— 1916 ... 96
——— 1917 ... 248
——— 1918 ... 98
——— 1919 ... 158
——— 1920 ... 166
——— 1921 ... 250
Ball Bearings. A. Marshall Arter, 1917 ... 157
Blackpool Sea Coast Defence Works. H. Banks, 1920 ... 284
Bridge Foundations in the East and the Sittang Railway Bridge, Burma Railways. A. S. Buckle, 1914 ... 251
'Bus *v.* Tram Controversy. W. Yorath Lewis, 1913 ... 20
By-Product Problem, A Survey of the Power. T. Roland Wollaston, 1918 ... 65
Cartridge, Uses of the Hydraulic Mining. James Tonge, 1914 ... 285
Chimneys, The Design of Tall. Henry Adams, 1911 ... 363
Clay, Experiments with, in its Relation to Piles. Alfred S. E. Ackermann, 1919 ... 37

PAGE

Clay, The Lateral and Vertical Pressure Effect of Piles in, H. R. Lordly, 1920 171
Clay, The Physical Propcrties of. Alfred S. E. Ackermann, 1920... 196
Clay, The Physical Properties of. Alfred S. E. Ackermann, 1921...87, 173
Coal, A Survey of the Power By-Product Problem. T. Roland Wollaston, 1918 65
Coal and its By-Products. J. R. L. Allott, 1921 157
Coal-Field, The South Eastern. B. L. Rigden, 1913 7
Coast Protection (See *Accretion*).
Coast Protection, The Winning of Tidal Lands in British Guiana. G. O. Case, 1921 177
Cohesion. Dr. H. Chatley, 1921 135
Colonies, as a field for Engineer work, (The). H. Conradi, 1911 ... 218
Concrete and Reinforced Concrete. H. M. Wilson, 1916 ... 139
——— Mixtures for Ferro-Concrete Work. T. J. Gueritte, 1918 33
Concrete, The Action of Sea-Water on. Prof. E. R. Matthews, 1920 ... ... 75, 109, 157
Corrosion (See *Iron*).
Council, Report of, 1910 293
——— 1911 409
——— 1912 344
——— 1913 278
——— 1914 345
——— 1915 284
——— 1916 272
——— 1917 358
——— 1918 216
——— 1919 316
——— 1920 312
——— 1921 255
Design of Continuous Beams, The. Ewart S. Andrews, 1916 ... 161
,, ,, ,, in Ferro-Concrete. H. Brodick ... 199
Dinner, Amalgamation, 1910 1
——— 1911 7
——— 1911 197
Drawing Office Organization. F. G. Woollard, 1911 231
Electrical Transmission of Power for Marine Transportation. W. P. Durtnall, 1912 267
——— Trolley vehicle system of railless traction. Henry C. Adams, 1912 35
Electricity from the Wind. A. H. Allen, 1910... ... ... 7, 19
Empire Development, Engineers and. C. R. Enock, 1910... 165, 177, 193
Energy from the Sun, The Utilization of. A. S. E. Ackermann, 1914 81
——— 1915 177
Engineering and Scientific Research. J. A. Fleming, 1916 ... 101
——— Practice, Some Modern, in America. R. W. A. Brewer, 1921 31
——— Troubles in Africa and their Solutions, Some. G. A. Becks, 1910 197
Engines, Two-stroke Cycle. R. W. A. Brewer, 1911 303
Esperanto, An International Language for Engineers. T. J. Gueritte, 1914 59
Explosives, Modern. Prof. J. Young, 1919 109
Ferro-Concrete (See *Reinforced5Concrete*).
Flood Prevention Works at Troon, Ayrshire. Prof. E. R. Matthews, 1920 75
Fuel Economy. A. E. A. Edwards, 1920 140
Gas, Petrol Air. E. Scott-Snell, 1911 73
Gas Works, The re-construction of a country. A. E. Whitcher, 1915 223

PAGE

Gold Medal, Recipients of President's from its Institution to date 74
Goods Clearing House System and Machinery Explained, The. Lord Headley, 1917 195
Harbours (See *Accretion*).
Heating and Ventilating Private Dwelling Houses. C. T. Alfred Hanssen, 1916 189
Heating and Ventilation. A. H. Barker, 1915 115
High Tensile Steel *versus* Mild Steel for Reinforcing Concrete. A. W. Shelf, 1917 131
Highways. C. H. Cooper, 1913 171
Hydraulic Separation, Studies in. J. M. Draper, 1920 ... 127
India, Irrigation in. R. H. Cunningham, 1914 205
Inspection of Materials (See *Testing*).
Intermittency: its effect in limiting electric traction for city and surburban passenger transport. Wm. Yorath Lewis, 1912 ... 121
Iron, Corrosion and Rusting of. Eric K. Rideal, 1913 239
Irrigation in India. R. H. Cunningham, 1914 205
Language, Esperanto for Engineers. T. J. Gueritte, 1914 ... 59
Law and Engineering, Some points of contact. S. G. Turner, 1915 195
Life Guards for Motor Vehicles. H. Conradi, 1916 7
Life in a British Internment Camp, 1917 287
Lighthouse Design and Construction. L. S. Spiro, 1915 ... 7
Lighting, Electric, of steam driven trains. E. Kilburn Scott, 1914 1
Ligno-Concrete. Gerald O. Case, 1912 83
Load, The Dynamic Increment of a uniformly distributed. Herbert Chatley, 1914 221
Machinery, Inspection and testing of Engineering Materials and. C. W. V. Biggs, 1910 133
Marine Transportation, Generation and Electrical transmission of power for. W. P. Durtnall, 1912 267
Materials (See *Machinery*).
Members, List of 137
Mineral Requirements of the British Iron and Steel Industries, The. Professor W. G. Fearnsides, 1917 1
Mineral Resources of the British Empire with regard to the Production of Non-Ferrous Industrial Metals, The. C. Gilbert Cullis, 1916 215
Mining, Uses of the Hydraulic Cartridge. James Tonge, 1914 ... 285
Modern Coal and Coke Handling Machinery: as used in the Manufacture of Gas. J. E. Lister, 1916 65
Modern Shipbuilding and Economy of Material. J. W. Isherwood, 1918 103
Modulus of Elasticity of thin flexible strips. F. H. Hummel, 1912 209
Motor Vehicles, Running costs of. R. W. A. Brewer, 1915... ... 51
Murmansk and Archangel Districts, Some Notes on the. B. L. Rigden, 1920 39
Nitrogen Products made with the aid of Electric Power. E. Kilburn Scott, 1911 9
Notes on Railway High-Capacity Wagon Wheel Axles. H. Kelway-Bamber, 1918 189
Obstacles to Post-War Trade Sir Richard Cooper, 1918 ... 169
Organization, Drawing Office. F. G. Woollard, 1911 231
Permanent Way on Railways, The Mechanical Installation and Upkeep of. T. J. Gueritte, 1911 249
Petrol Air-Gas. E. Scott-Snell, 1911... 73
Pit Props and Head Trees, The Strength of Prof. Henry Adams, 1919 213

PAGE

Pollution, Subterranean erosion of water-bearing strata in relation to. Spencer Sills, 1912 ... 7
Possibilities in Engineering. L. S. Spiro, 1913 ... 163
Post-War Trade, Obstacles to. Sir Richard Cooper, 1918... 169
Power, Tidal Waters as a source of. C. A. Battiscombe, 1913 115
Practical Roadwork in the United Kingdom. E. G. Wilson, 1917 275
Presidential Addresses. Diogo A. Symons, 1910 ... 25
——— F. G. Bloyd, 1911 ... 37
——— John Kennedy, 1912 ... 21
——— Arthur Valon, 1913 ... 69
——— H. C. H. Shenton, 1914 ... 30
——— Norman Scorgie, 1915 ... 24
——— Percy Griffith, 1916 ... 23
——— Henry C. Adams, 1917 ... 115
——— W. B. Esson, 1918 ... 9
——— W. Noble Twelvetrees, 1919 ... 8
——— Burnard Geen, 1920 ... 10
——— The Rt. Hon. Lord Headley, 1921 ... 7
Professional Topics, Current. Henry C. Adams, 1910... 203
Pumps, Testing Centrifugal. F. H. Hummel, 1913 ... 149
Rail Plateways. G. Noble Fell, 1912 ... 199
Railless Traction, The Trolley vehicle system of. Henry C. Adams, 1912 ... 35
Railway Coy. (R.E.) in France and Belgium during the War, Some Engineering Work done by the 227th. R. H. Cunningham, 1290 ... 43
Railway Engineering in China, Notes on. G. L. B. Newmarch, 1917 ... 255
Railway, The Promotion and Construction of the London and Birmingham. F. G. Bloyd, 1911 ... 200
Railways, High-Speed. E. W. Chalmers Kearney, 1917 ... 307
Railways, The Mechanical Installation and Upkeep of Permanent Way on. T. J. Gueritte, 1911 ... 249
——— Safer, Quicker and Cheaper. C. R. Enock, 1911 ... 267
Reinforced Concrete retaining walls. E. R. Matthews, 1910 ... 181
——— Test deflections in. P. J. Waldram, 1912 ... 311
Report of Council, 1910 ... 293
——— 1911 ... 409
——— 1912 ... 344
——— 1913 ... 278
——— 1914 ... 345
——— 1915 ... 284
——— 1916 ... 272
——— 1917 ... 358
——— 1918 ... 216
——— 1919 ... 316
——— 1920 ... 312
——— 1921 ... 255
Reservoirs, A Short Paper on. Basil C. Light, 1917 ... 261
Resettlement of Officers in Civil Life. A. Stewart Buckle, 1919
Retaining Walls, Reinforced Concrete. E. R. Matthews, 1910... 181
Rivers and Waterways, National Control of. Reginald Brown, 1913 ... 155
Roads Development Act, 1909, The Working of. Reginald Brown, 185
1910 ... 265

PAGE
Roads, Main ; Past and Present. F. Grove, 1915 81
——— Up-to-date. R. O. Wynne-Roberts, 1910 101
Rolling, Resistance to. Herbert Chatley, 1912 179
Roll of Honour, 1917 361
Rusting (See *Iron*).
Sewage and its Precipitation : Facts and Fallacies from Laboratory and Practical Tests. Reginald Brown, 1916 37
——— and its Precipitation : Further Experiments. Reginald Brown, 1917 289
Sewage Disposal Ideals. W. C. Easdale, 1910 43
Sewer from Battersea to Deptford, Construction of a L.C.C. low-level main. J. P. Harris, 1912 223
Sewer Ventilation and Health. William Brown, 1919 247
Sewerage and Sewage Disposal Works, Northwich. W. M. Beckett, 1921 223
Shipbuilding and Economy of Material, Modern. J. W. Isherwood, 1918 103
Slaughter of Animals, Mechanical Appliances for the painless. S. M. Dodington, 1914 309
Slaughter-Houses, Public. S. M. Dodington, 1910 229
Solar Energy, The Utilization of. A. S. E. Ackermann, 1914 81
——— 1915 177
Status Prize Essay. Wm. Ransom, 1913 91
Steam Control Device, A Simple Low Pressure. J. W. Smith, 1920 157
Steel, Heat Treatment of. C. O. Bannister, 1919 163
Sun, Utilization of Energy from the. A. S. E. Ackermann, 1914... 81
——— 1915 177
Surveys, Reconnaissance. L. S. Spiro, 1913 145
TESTING AND INSPECTION OF ENGINEERING MATERIALS AND MACHINERY. C. W. V. Biggs, 1910 133
Tidal Lands, The Winning of, in British Guiana. G. O. Case, 1921 177
Tides, as a source of Power. C. A. Battiscombe, 1913 115
Town-planning from an Engineering standpoint. E. R. Matthews, 1912 235
Traction Intermittency ; its effect in limiting. Wm. Yorath Lewis, 1912 121
——— Trolley vehicle system of railless. Henry C. Adams, 1912 35
Trade Unionism as applied to Professions. A. B. Howes, 1914 ... 229
Traffic Problem, The London. W. Yorath Lewis, 1913... ... 20
Trains, Electric lighting of steam-driven. E. Kilburn Scott, 1914 1
Transport, Mechanical in the War. Capt. Richard Twelvetrees, 1919 279
Turbines (See *Water Power*).
Turbines, Extraction. C. H. Naylor, 1921 208
Tyre, The Motor Car Pneumatic. J. C. Ferguson, 1921 60
Vacuum Railways, High-Speed Land and Sea. Arthur Oates, 1917 233
Vehicles, Running Cost of Motor. R W A Brewer, 1915 ... 51
Ventilation and Heating. A. H. Barker, 1915 115
Versailles, The Unknown. T. J. Gueritte, 1919 190
Wagon Wheel Axles, Notes on. H. Kelway-Bamber, 1918 ... 189
War on and under the Sea. Edwin Hall, 1918 153

PAGE
WATER bearing strata in relation to pollution, Subterranean Erosion of. Spencer Sills, 1912 7
WATER Conservancy, The Administrative Aspect of. W. R. Baldwin-Wiseman, 1911 120
WATER Power, The Modern Development of. A. Steiger, 1915 233
——— Supplies, Protection of. H. C. H. Shenton, 1911 ... 157
——— Supplies, Public. Percy Griffith, 1915 157
——— Supply of Greater New York, Notes on. William T. Taylor, 1914 ... ... 167 & 241
WATERWORKS, Moulmein. P. G. Scott, 1910 79

NOTE.—A complete index to the Transactions of the old Society of Engineers will be found in the last volume (1909) published by that Society, and the volumes of Transactions of the Civil and Mechanical Engineers' Society are also indexed.

TA
1
S67
1921

Society of Engineers,
London
Journal

~~Physical &
Applied Sci.
Serials~~

Engineering

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY

ENGIN STORAGE